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TRW INC.

USERS' MANUAL

For Use With TRW Space Radiator-Condenser Design and Performance Analysis Computer Programs

Prepared Under Contract No.
NAS 9-4884
for
Propulsion & Power Division
NASA Manned Spacecraft Center
Houston, Texas

April 1966

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ABSTRACT

This report presents the analyses required to design and analyze a direct space condenser-radiator of general geometry utilizing any working fluid including a combination of a condensable vapor and noncondensable gas. These analyses are then reduced to a computer-usable form and a series of five computer programs (in Fortran IV) capable of designing and analyzing these radiators are described. Lastly, the instructions for the operation of these computer programs are delineated.

These computer programs consider such items as: flat plate, triform, cruciform, cylindrical, and conical panel configurations; operation in a variable gravitational field (including zero g); automatic bypass and segmentation to control outlet temperature; fixed inventory or pressure regulated condensers; non-uniform sink temperature; and single and parallel tube flow stability.

TABLE OF CONTENTS

TABLE OF CONTENTS (continued)

TABLE OF CONTENTS (continued)

TABLE OF FIGURES

TEXT (Figures appear in Figures Section)

APPENDICES (Figures appear at the end of each Appendix)

TABLE OF FIGURES (continued)

TABLE OF FIGURES (continued)

1.0 INTRODUCTION

The design of extended surface rejection of waste heat from space vehicles lends itself readily to optimization by computer techniques. This is a result of the radiator weight (the parameter normally minimized within various constraints) being a function of the number of tubes, tube diameter, tube length, and fin width/thickness and the interaction of these factors for a given design condition. Furthermore, in many cases, the weight of these radiators is a significant fraction of a total vehicle weight. Consequently, many computer programs have been conceived for the purpose of designing these radiators in an effort to minimize their weight.

A problem of size and complexity results, however, when one attempts to devise a single computer program to satisfy the requirements of all systems in need of a means of rejecting waste heat in space. Figure 1, as an example, groups some of the heat-rejection-requiring systems according to temperature level and heat rejection mode. It is obvious that a single computer program applicable to even the small number of types shown in Figure 1 would be unwieldy. As a result, the computer programs developed to date are limited to a specific type or types of systems based on the need of the sponsor. As examples, References 1, 2 and 3 consider a $0^{o}R$ sink temperature, which, for the purpose of the program (high temperature liquid metal Rankine cycle power system), is acceptable but results in large error when applied to the systems radiating at lower temperatures to a non-zero sink. Some programs (Reference 1 and 3) are limited to the consideration of certain fluids whose properties are built into the program. Others consider only single phase fluids, non-isothermal rejection of heat (Reference 4), while others consider only two-phase condensing processes rejecting heat isothermally (References 1, 2 and 3).

In addition to this problem of generality, comparatively little effort has been expended in the computer analysis for off-design conditions of a previously defined radiator.

Early in 1965, the Manned Spacecraft Center of the National Aeronautics and Space Administration had a need for a computer program or programs to design <u>and analyze</u> direct radiating condensers for (a) high and low temperature Rankine cycle power systems, (b) refrigeration cycles for environmental control systems, and (c) fuel cell power systems.

Category (a) had been extensively treated in the high temperature area in the literature, but the low temperature area and category (b) was somewhat less completely covered, and no treatment of category (c) was found. In addition, very little consideration had been given to the off-design performance of radiators, most of these being limited to a specific system or radiator design.

As a result, in June 1965, NASA/MSC awarded a contract to the Equipment Laboratories Division of TRW to perform the analyses and write and debug the program(s) necessary to satisfy this need.

After evaluating the differences and similarities in the requirements of (a), (b) and (c) above, it was decided to separate the problem into five programs as follows:

I - Fuel Cell Design Program

II - Isothermal Design Program

III - Primary/Secondary Design Program

IV - Fuel Cell Performance Analysis Program

V - Isothermal Performance Analysis Program

A detailed description of the operation of each of these programs can be found in Section 4.0.

In addition to the normal capabilities of considering various tube numbers, diameters and lengths and fin widths and thicknesses, these programs consider: a) non-constant sink temperature such as might be seen by a cylindrical radiator in a lunar orbit, b) effects of gravity environment on flow stability, c) automatic segmentation or bypass to control condenser outlet temperature, d) constant liquid inventory or constant pressure regulation in the condenser, and e) a wide range of tube/fin and panel configurations.

2.0 DISCUSSION

The computer programs developed under this contract are applicable to direct condensing fin and tube radiators in a space environment. They consider the desuperheating of the vapor, condensing of the vapor and the subcooling of the condensate. In the special case of non-isothermal condensation of water vapor in hydrogen gas (fuel cell), the effect of desuperheating, condensing, and diffusion are considered.

The systems to which the design and analyses are applicable are: (a) high and low temperature Rankine cycle electrical power systems, (b) active environmental control systems, and (c) fuel cell power systems all employing direct condenser radiators. Schematics of these systems are shown in Figure 2.

Much similarity exists in systems (a) and (b), but system (c) requires special treatment since the presence, in large quantity, of the noncondensable hydrogen and the resultant incomplete condensing of the input vapor requires a unique series of considerations. As a result, the environmental and Rankine systems have been treated identically in the programs and separate from the fuel cell, or sometimes referred to herein as the non-isothermal system.

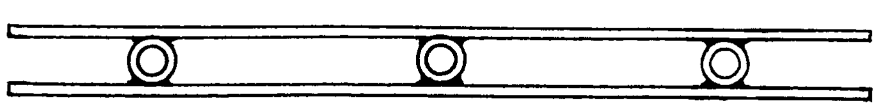
The primary/secondary concept is a special case of the environmental/Rankine case capable of operation in high "g" fields. Basically, it is a series combination of a parallel and a single tube direct radiator-condenser which combines the lightness of the former with the stability of the latter. This concept was conceived of, developed, and successfully operated with condensate flow in opposition to 1 g on the Sunflower I contract between the Lewis Research Center of the National Aeronautics and Space Administration and TRW. The theoretical background of this approach is contained in Section 3.3 and Appendix B-5.

2.1 Configurations

Three types of tube/fin construction are considered: central fin, open sandwich, and closed sandwich as shown below.

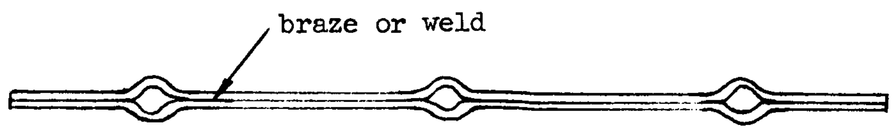
Central Fin

Open Sandwich



Closed Sandwich

The central fin construction is the classical geometry considered in most analytical exercises. From a fabrication standpoint, however, it is less practical than either of the other two geometries. An alternate fabrication of this geometry is shown below.



Alternate Central Fin Construction

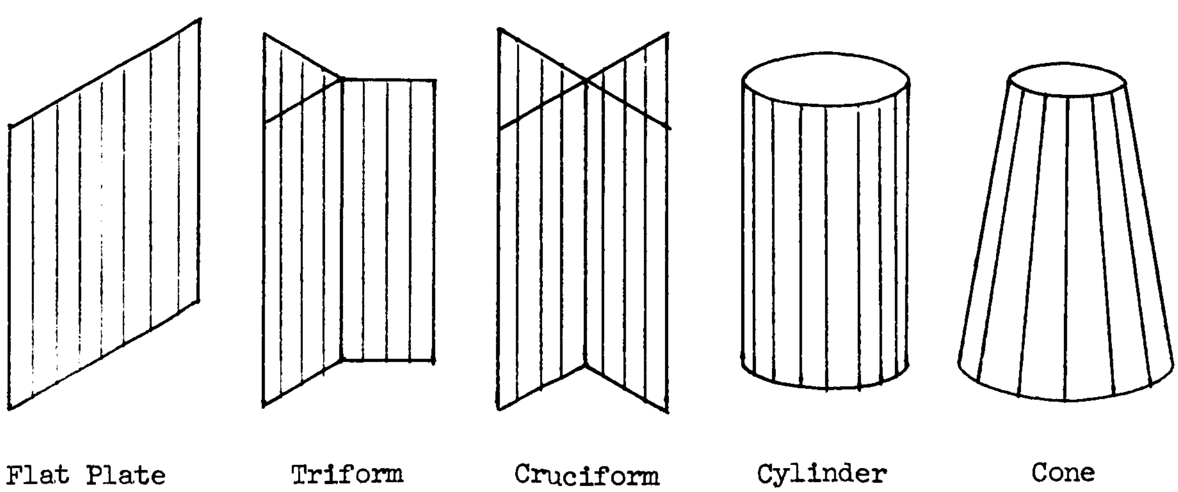
This has the disadvantage of requiring the same material be used for tubes and fins at approximately the same thickness but is more easily fabricated.

The open sandwich construction is the most easily fabricated lending itself to tube-to-fin furnace brazing, torch brazing, or welding, depending on the tube and fin materials, strength requirements, and/or furance capacity. Its use in a conical or cylindrical panel configuration with the tubes on the inside makes maximum use of the meteoroid protection effect of the fins.

The closed sandwich has the advantages of strength and the meteoroid protection afforded by the fin location for any panel configuration but is somewhat more difficult to fabricate than the open sandwich.

Although other variations in tube/fin geometry exist, most notably a closed sandwich honeycomb, the programs contained herein are necessarily limited to the geometries discussed.

Five panel configurations are considered in conjunction with the three tube/fin types: flat plate, triform, cruciform, cylinder (or segment) and cone (segment and/or frustrum). These are sketched below.



The panel choice, of course, is determined by the envelope available. In general, the flat plate will be the lightest for a given heat rejection but will require greater envelope dimensions. Conversely, the cone and cylinder may be heavier but will fit into a smaller envelope. The triform and cruciform fall between the flat plate and cone/cylinder with regard to weight and envelope size. In short, it can be said that the optimum panel configuration can be determined only in the specific case.

Figure 3 shows which of these panel configurations are considered in each program, (denoted with an X).

In cylindrical and conical panels using closed sandwich tube/fin geometry, the inner fin thickness is specified by the designer in all programs and is not considered to effect or affect heat transfer. With the same panel configurations employing an open sandwich, the tubes are always assumed to be on the "inside". A single inlet and single outlet are assumed in all panel configurations, and in all cases, the three tube/fin configurations may be considered.

2.2 Operating Environment

Any vehicle traveling outside the earth's atmosphere will encounter conditions unlike those on the ground. These conditions are fairly well understood and include: exposure to meteoroids, loss of convection-type external heat rejection as a result of the vacuum environment, low or zero "g" acceleration levels, and exposure to high energy electrically charged particles. The last characteristic is not considered in the computer programs, but the others are handled in the manner discussed in the following paragraphs.

2.2.1 Meteoroid Protection

Meteoroids of varying size, density and velocity are one of the hazards encountered by space vehicles. If the integrity of a particular component would be diminished or lost due to a puncture resulting from a collision with one of these meteoroids, suitable precautions must be taken. This is precisely the case with condenser-radiator tubes.

Meteoroids, of cometary and asteroidal origin, travel in eccentric orbits within our solar system. About 20% of those near the earth are members of a meteoroid shower, whose behavior can be predicted and, consequently, they can be avoided. The remaining 80%, however, are sporadic in nature and must be treated on a probability basis. Meteoroid protection requires the determination of 1) the frequency of the meteoroids, 2) the mass, density and velocity of the meteoroids, and 3) the penetrating power assuming the mass, density and velocity are known. Many earth observations and satellite experiments have been performed to determine (1) and (2), but most have had significant limitations of time, area or sensitivity, i.e., ability to count only meteoroids above a certain minimum size. Many earthbound experiments have investigated (3) but have been limited in significance because meteoric velocities (28 to 40 km/sec) have not

been attainable. Despite these shortcomings, some assessment of the problem must be made before intelligent designs of future systems can be undertaken. Reference 5 appears to be the best assessment to date.

After surveying available data and experimental results, Reference 5 concludes with the equation:

$$t_a = 2\,\bar{F}a \left(\frac{\rho_p\, 62.45}{\rho_a}\right)^{\frac{1}{2}} \left(\frac{V_p}{c}\right)^{2/3} \left(\frac{6.747 \times 10^{-5}}{\rho_p}\right)^{1/3} \left(\frac{\alpha A_v \tau}{-\ln P_{(o)}}\right)\left(\frac{1}{\beta + 1}\right)^{1/3} \quad (1)$$

where

t_a = thickness of required armor, in.

$\bar{F}$ = 1.0

a = 1.75; correction for a finite target, i.e., the target that will be penetrated by a projectile is 1.75 times the depth of penetration in an infinitely thick target (due to spalling).

ρ_p = meteoroid density, 0.44 gm/cm^3

ρ_a = armor density, lb/ft^3

$\bar{V}_p$ = meteoroid velocity, 98,400 ft/sec

c = sonic velocity in armor, ft/sec or $12\sqrt{\dfrac{E_t\, g_c}{\rho_a}}$

E_t = modulus of elasticity of armor, lb/in^2

g_c = gravitational constant, 32.2 ft/sec^2

α = 5.3×10^{-11} ft^2-day (defines flux/mass relationship of meteoroids)

β = 1.34

A_v = outside area of vulnerable surface: tubes, headers, etc. in a radiator

τ = exposure time, days

$P_{(o)}$ = desired probability of no penetration by a meteoroid in τ days

Equation (1) is included in the design programs to calculate the necessary meteoroid armor. This calculation can be bypassed, if desired, by specifying a tube wall thickness in the input data.

In the programs, the headers are assumed to be protected from meteoroid impact by structure and their area is not considered vulnerable. The use of bumper-type

meteoroid protection, i.e., lesser amounts of protection separated from the vulnerable area, is not considered in the programs since gross uncertainties currently exist in this approach.

2.2.2 Vacuum Environment

The high vacuum environment of space has an effect on the long-term surface characteristics of the exposed areas. But of even more significance to a space condenser-radiator is the loss of external convection. Heat rejection becomes a matter of radiation to the environment of space. This thermal environment is comprised of planets emitting infra-red and reflecting solar energy and the sun emitting direct solar energy. The level of incident radiation from each of these sources is a function of the radiator's location and attitude in space. In each design program, the magnitude of the radiation and the absorptivity of the radiator surface to the radiation can be specified in the input data. In lieu of these radiation level and absorptivity combinations, a sink temperature may be specified (see paragraph 3.1.2). Furthermore, in the performance analysis programs, up to twelve different levels of incident energy may be considered simultaneously (such as that which may be seen by a cylindrical radiator).

In all cases the computer programs add this energy absorbed from the environment to the heat rejection requirement of the radiator.

2.2.3 Acceleration Environment

Almost all ground-based condensers rely on gravitational attraction to transport the condensate to the desired location. In the case of Rankine cycle central power stations, gravity also supplies a portion of the pump suction pressure. In space travel, however, the majority of any journey will be spent in zero or near-zero gravity, and, consequently, some other means of condensate transport and pump inlet pressure supply must be found.

To solve the first problem, the vapor is condensed in small tubes such that the vapor velocity is great enough to produce a drag on the condensate and drive all the liquid to the condenser outlet. This problem is magnified if orbital transfer or mid-course correction maneuvers cause accelerations in directions which require the vapor to move the condensate "uphill". In this event, the vapor drag must be even higher to overcome the external body forces. In the computer programs, the vapor velocity necessary to achieve not only condensate transport, but multiple tube stability, is observed as a minimum. These considerations are discussed in detail in paragraph 3.2.4.

The problem of adequate NPSH in space Rankine cycles is normally solved by designing the condenser to operate at a pressure level which will maintain the pump prime. In some cases, this pressure level is above that desired for system optimization. This pump inlet pressure is fixed in the design programs by the user when he specifies the condenser inlet pressure and condenser pressure drop in the inputs.

3.0 ANALYSIS

In designing or analyzing the performance of extended surface space radiator condensers, two major criteria have to be dealt with and satisfied. They are thermal behavior (heat transfer and thermodynamics) and fluid dynamic behavior (pressure drop and flow stability).

The general approach taken in the design programs is to determine applicable combinations of geometry (condensing length, diameter, number of tubes, etc.) according to fluid dynamic criteria and then, based on the heat rejection requirement, determine suitable finning for each combination. In the performance analysis programs, the previously-defined geometry, environment, and flow rate are used to determine the operating conditions and behavior. In both types of programs, the equations governing heat transfer and fluid dynamics are identical; only their sequence is varied depending on the known quantities.

3.1 Heat Transfer and Thermodynamics

The mechanics of heat rejection in a space radiator involves convection from the fluid to the tube wall, conduction from the tube to the fins, and radiation from the tubes and fins to the environment. These three modes of heat transfer are discussed in Sections 3.1.3, 3.1.1 and 3.1.2, respectively.

3.1.1 Nodal Point Method

General analytical expressions relating heat flows, temperatures and geometries of space radiators have been derived in the literature (i.e., references 6, 7, 8 and 9). These expressions, however, are usually in the form of differential equations requiring numerical integration. Due to this reason and the generalities in geometry and flow conditions to be covered by these programs, a nodal point method was employed.

Symmetry allowed one-half of an externally finned tube to be considered. This geometry was further subdivided into a series of nodes, the fins having four nodal points per section and the tube two. In addition, the isothermal condenser was assumed to have one section along the condensing length and two along the subcooler length and the non-isothermal (fuel cell) radiator, three along the condensing length. The nodal point locations for the three fin-tube configurations are shown in Figure 4.

For a steady state application, the summation of all heat flows by conduction, radiation, and/or convection into a node is equal to zero. By summing the heat flows about each node, a set of nonlinear simultaneous equations relating geometry and temperature is obtained. A typical set of equations for a single fin nodal point is shown in Appendix A-1. To assure a fast converging solution of these simultaneous nonlinear equations, a special computer subroutine was devised.

3.1.2 Radiation Heat Transfer

The net radiative heat exchanged between two energy sources is a function of

their temperatures, surface properties, the spectral distribution of the energies, and the "view factors" between the two sources. The sources of radiation encountered by space radiators will be the sun (solar), planets (albedo and infrared) and on-board sources (infrared). Since absorptivity has a strong spectral dependence and the above sources show intensity peaks at at lest two widely different wave lengths (visible and infrared ranges), it was decided to use two values for surface absorptivities: solar, or high temperature, absorptivity values for solar and planet albedo radiation and thermal, or low temperature, absorptivity values for planet thermal and on-board radiation. The radiator surfaces are considered gray within each of the two spectral regions and, hence, the surface emissivity values will be equal to the thermal absorptivity values. The radiation emitted from the radiator is considered to be diffuse; i.e., the magnitude is constant for all angles. Similarly, no angular dependence is assumed for the solar and thermal absorptivities.

Since the tube and fins of space radiator-condensers are not continuous, flat surfaces and certain panel configuration cause panels of the same radiator to "see" each other, geometric configuration factors and energy reflections have to be investigated.

View factors from incremental fin areas (nodal points, see Section 3.1.1) to adjacent tubes are derived for all three fin-tube configurations in Appendix A-2. Also, for the closed sandwich configuration (see Figure 4), view factors from an incremental fin nodal point to opposite fin nodal points are derived. The view factors used are actually those from the mid-point of the nodal points to tubes and opposite fin nodal points; when these were compared with the integrated view factor from the entire nodal point, it was found that the first and simpler version could be used with negligible error.

A further simplification was made in that no radiant energy exchange between fins and tubes was considered, but rather the tubes and fins merely blocked each other's view to space. In the configurations used in this analysis, the tube/fin view factor value decreases as temperature difference increases (moving along the fin perpendicular to and away from the tube) and the product of view factor and difference of the fourth power of temperatures for typical radiator-condensers in calculating net radiant energy exchange between fin and tube results in negligible values compared to heat conduction and radiation to space. For similar reasons, fin-to-fin net radiant energy exchange for the closed sandwich configuration was also neglected. Examples of the errors involved in these simplifications are shown in Appendix A-2.

Lastly, reflective tube/fin interchange (for normal geometry and surface properties) was shown to have insignificant effects on total heat transfer in Reference 27. Accordingly, this effect was also neglected.

Based on the above considerations and using the derived fin-to-tube view factors in conjunction with view factor algebra, a set of view factors of fin nodal points to space was derived. Figures A-2 and A-3 (Appendix A-2) show the derived factors for each fin segment in generalized terms. Also included are the tube-to-space view factors.

Figure A-4 shows local view factor from panels of triform and cruciform configurations to space. As can be seen from the figure, integrated values for each case of .866 and .707, respectively, derived in Appendix A-3 can be used as constants over the complete panel surfaces without introduction of sizable overall error.

For this analysis, all conical and cylindrical radiators are assumed to have blocked ends and negligible internal radiant interchange and headers are assumed to be located in such a way as to result in negligible radiant energy loss.

In writing the net radiant exchange between energy sources and radiator segments, an equivalent sink temperature is used. (Physically, the equivalent sink temperature is that temperature a surface would attain were it in thermal equilibrium with the environment with no other heat input to the surface except from the environment.) This sink temperature can either be specified or derived based on incident fluxes and the absorptivities of the radiator surfaces to these fluxes. The equation for effective sink temperature is derived as follows (see Nomenclature section for explanation of symbols):

$$Q = F_{sp} \sigma \epsilon \ T^4 - F_{sp} \left[\alpha_s \ (Q_s + Q_a) + \alpha_t \ Q_t \right]$$

where Q = heat exchanged per unit area and time.

The form using an equivalent sink temperature, T_s, would be:

$$Q = F_{sp} \sigma \epsilon \left[T^4 - T_s^{\,4} \right]$$

$$F_{sp} \sigma \epsilon \ T_s^{\,4} = F_{sp} \left[\alpha_s \ (Q_s + Q_a) + \alpha_t \ Q_t \right]$$

Since $\epsilon = \alpha_t$,

$$T_s = \left\{ \frac{1}{\sigma} \left[\frac{\alpha_s}{\alpha_t} \ (Q_s + Q_a) + Q_t \right] \right\}^{1/4} \tag{2}$$

Equation (2) is used in the programs to determine the sink temperature(s) in the event the incident heat fluxes are specified.

3.1.3 Condensing Coefficients

Basically, two mechanisms can occur when vapors condense: dropwise or filmwise condensation. Fluid type and/or surface material and conditions primarily determine the type of condensation. From the types of fluids and compatible materials considered in this study, only mercury will be considered non-wetting, i.e., condense in a dropwise manner. All other fluids are thought of as wetting with resulting filmwise condensation.

Since the presence of a noncondensable gas in condensation of vapors effects the condensation coefficient, special consideration in that area has to be given to a fuel-cell direct radiator-condenser.

3.1.3.1 Fuel-Cell

When a mixture of noncondensable gas and condensable vapor comes in contact with a surface colder than the dew point of the mixture, condensation will occur. For film-type condensation, a thin liquid film of condensate will form on the surface and a gas and vapor film will separate the main body of the mixture and the condensate layer. The gas and vapor film will have a lower vapor concentration than the main body (reference 10). Because of the partial pressure difference of the vapor between the main body and the liquid interface, the vapor diffuses through the gas film to condense at the interface. Thus, sensible heat of the gas and vapor and latent heat of the vapor are transferred through the condensate layer but only sensible heat passes through the gas layer. The condensation rate is, therefore, governed by the law of diffusion of vapor through a film of noncondensable gas while sensible mixture cooling is governed by usual modes of heat transfer, i.e., conduction and convection.

An analysis of a combined heat transfer coefficient for a fuel cell direct radiator-condenser with the noncondensable gas being hydrogen and the condensable vapor being steam was performed. In this analysis the sensible heat transfer coefficient and the ratio of latent heat transfer coefficient to the sensible heat transfer coefficient were determined. The combined coefficient can then be expressed

$$h_{combined} = h_{sensible}\left(1 + \frac{h_{latent}}{h_{sensible}}\right)$$

This approach was taken since h_{latent} is difficult to determine independently, whereas $h_{sensible}$ is comparatively straightforward and the ratio $h_{latent}/h_{sensible}$ can be obtained realizing the mechanism for both are coupled by certain physical laws as discussed above. The results of the analysis showed that $h_{latent}/h_{sensible} \ggg 1$ and the resulting $h_{combined}$ was high enough that the resistance to heat flow would be small (for the range of conditions expected) compared to the radiation resistance. As a result, a constant $h_{combined}$ of 1000 Btu/hr-ft^2-$^\circ$F was used for the hydrogen water-vapor mixture fuel cell direct radiator-condenser. The analysis is contained in Appendix A-4.

3.1.3.2 Liquid Non-Metals

The formation of a condensate film on a surface whose temperature is below the saturation temperature of the vapor creates a heat flow resistance through which the latent heat of the vapor must pass. The overall resistance can be considered to consist basically of a resistance at the liquid-vapor interface and a resistance due to the condensate film. For common type fluids, Prandtl No. $>$ 0.5, the liquid vapor interface resistance is negligible compared to the resistance due to the condensate film (Reference 10). The liquid non-metals considered in this analysis fall into this category.

Expressions for condensing coefficients applicable to fluids with a Prandtl No. $>$ 0.5 have been derived by Nusselt (Reference 11) for laminar condensate flow and expanded by Kirkbride (Reference 12) for turbulent condensate flow. Neither expression accounts for the case in which the velocity of the uncondensed vapor is substantial compared with the velocity of the condensate at the vapor-condensate interface. Frictional vapor drag on the film affects the film's velocity and thickness and, therefore, the heat transfer coefficient. Experimental work by Carpenter and Colburn (Reference 13) shows that in the latter case coefficients ten times higher than those obtained using Nusselt's and Kirkbride's expressions were measured. In the above reference, Carpenter and Colburn derive an expression, based on data for condensation of a saturated vapor flowing downward in a water-cooled tube at high velocities, using the shear stress, τ_w, at the vapor-liquid interface but basing this stress on the equation for dry tubes:

$$\tau_w g_c = \frac{f G_v^2}{2 \rho_v}$$

Plotting $\tau_w g_c$ vs. $\dfrac{h_c \mu_c}{k_c \rho_c^{1/2}}$ based on experimental results gives:

$$h_c = .065 \left[\frac{c_p \rho_c k_c f}{2 \mu_c \rho_v} \right]^{1/2} G_v$$

and in terms of vapor velocity:

$$h_c = .065 \left[\frac{c_p \rho_c \rho_v k_c f}{2 \mu_c} \right]^{1/2} U_v \tag{3}$$

where U_v = vapor velocity.

This equation should not be used for fluids with very low Prandtl numbers (liquid metals) or very high Prandtl numbers (viscous oils, etc.). In using the above expression, it should be remembered that two simplifying assumptions were made: first, the friction factor is based on dry pipe data and, second, an average value of vapor velocity is employed.

3.1.3.3 Liquid Metals

Although experiments have substantially borne out the theoretical predictions for condensing coefficients of common fluids (Prandtl No. $>$ 0.5), the same cannot be said for liquid metals. The small amount of data from various investigators on condensation of metallic vapors all have one thing in common: the values for condensing coefficients obtained from experiments is up to an order of magnitude lower than the values predicted by Nusselt's, Kirkbride's

and Carpenter and Colburn's expressions. As References 11 and 14 point out, the cause of this discrepancy is that the governing resistance to heat flow from the vapor core to the tube wall must be at the liquid-vapor interface and is not due to the film thickness. The latter assumption was used by Nusselt, Kirkbride and Carpenter and Colburn.

Rohsenow (reference 11) uses the condensation coefficient, σ , (fraction of molecules striking the surface which actually do condense) to develop expressions for two Nusselt numbers, one based on the vapor to film temperature drop and the other based on the film to tube wall temperature drop. These expressions are complex and would require an iterative solution technique if used with a nodal point method. Values for σ for metallic vapors are scarce and those reported from separate sources show large variations for the same vapor.

Since condensing coefficients for metallic vapors have relatively high values, the temperature drop from the vapor core to the tube wall is small when compared to the operating temperature level. Hence, a sizable percentage change in the condensing coefficient will have a negligible overall effect when applied to a radiator-condenser as considered in this analysis. Based on the above findings and assumption, constant values, rather than analytical or empirical expressions, for liquid metal condensing coefficients were used.

Based on experimental data in references 11 and 14, and considering typical expected operating ranges, a constant value of 5000 Btu/hr-ft^2-$^\circ$F for the condensing coefficient of mercury vapor was chosen. Similarly, from References 11 and 14 constant values of 2000 Btu/hr-ft^2-$^\circ$F for the condensing coefficient of potassium and rubidium vapors were chosen. These constants were used in the programs for the liquid metals, but equation (3) was used for liquid non-metals.

3.1.4 Subcooler Convection Coefficient

In condensers, the removal of sensible heat from the liquid condensate is termed subcooling. In multiple tube radiator-condensers where complete condensation of a single fluid occurs, this subcooling usually takes place in an extension of the condensing tube.

As expected, the mode of heat transfer and, therefore, the value for the heat transfer coefficient, depend largely on whether the flow of the condensate is laminar or turbulent. For fully developed laminar flow in pipes, the mode of heat transfer is conductive in nature and the dimensionless ratio (hD/k), or Nusselt number, takes on a constant value if longitudinal conduction is insignificant.

In fully developed turbulent flow, the mode of heat transfer is both conductive (in the laminar sublayer) and convective (in the buffer layer and turbulent core). The heat transfer coefficient is then definitely a function of the Reynolds number (boundary layer determination) and Prandtl number (ratio of molecular transfer of momentum to molecular transfer of heat).

A certain length of tubing is needed before the laminar and turbulent boundary layers build up to a constant thickness, i.e., before fully developed laminar or turbulent flow is reached. Since the boundary layers are thinner in this entrance region, the Nusselt numbers are higher than in the fully developed case. The build-up of these boundary layers is strictly a function of fluid dynamics (for constant fluid properties) and is not influenced by heat transfer. Eckert (Reference 15) shows that, for smooth entry, circular pipes, the entrance length, L_e, required to reach fully developed laminar flow is a function of the Reynolds number, Re, and tube diameter, D. This function can be expressed as $L_e = .0288$ D Re. In the turbulent case, the boundary layer thickness increases faster and, therefore, a shorter entrance region results.

In a radiator condenser where the liquid flow starts from a highly active (due to impinging condensate) liquid-vapor interface, this entrance effect is assumed to have only slight effects.

3.1.4.1 Liquid Non-Metals

For laminar flow (Reynolds number, $(Re) < 2300$) of liquids flowing in pipes, the heat transfer coefficient is independent of the Prandtl number if longitudinal conduction can be neglected. This assumption is sound for liquid non-metals considered in this analysis. From Reference 15, a constant average Nusselt number, hD/k, equal to 5.0 was chosen for laminar flow in a subcooler.

For turbulent flow ($Re > 2300$), the effect of the Prandtl number on the heat transfer coefficient warrants a separate investigation for non-metallic liquids ($Pr \geq 1$) from that for metallic liquids ($Pr << 1$). For liquid non-metals the molecular transfer of momentum is more intense than the molecular transfer of heat. The thickness of the thermal boundary layer is less than the thickness of the dynamic layer, and as a result, the turbulent transfer of heat in the vicinity of the viscous sublayer becomes important.

Reference 16 gives an empirical expression for the Nusselt number derived by Dittus and Boelter for cooling of fluids in turbulent motion ($Re > 2300$)

$$Nu = \frac{hD}{k} = .023\,(Re)^{.8}\,(Pr)^{.3} \qquad (4)$$

and the fluid properties are determined at the "cup" temperature. The use of this equation results in some inaccuracy for Reynolds numbers from 2300 through 6000 (transition region). For this region H. Hausen (quoted in Reference 17) derived an expression for an average Nusselt number:

$$Nu = .116 \left[(Re)^{2/3} - 125\right] (Pr)^{1/3} \left[1 + \left(\frac{d}{L}\right)^{2/3}\right] \left(\frac{\mu_B}{\mu_W}\right)^{.14}$$

where μ_B = absolute fluid viscosity evaluated at the bulk fluid temperature

μ_W = absolute fluid viscosity evaluated at the tube wall temperature.

The evaluation of μ_w at the wall temperature and the dimension "L" (length from tube inlet) make this expression difficult to apply to the nodal point method employed in this analysis. As a result, the simpler Dittus-Boelter equation (4) was employed with only small sacrifice in accuracy in the 2300-6000 Reynolds number range.

3.1.4.2 Liquid Metals

Experimental results (Reference 18) indicate that the Nusselt number does not reach a constant value for laminar flow of liquid metals as it did for liquid non-metals. The main reason for this is assumed to be the fact that longitudinal conduction is comparable to radial conduction.

For turbulent flow for fluids with Prandtl No. $\ll$ 1.0, such as liquid metals, the molecular transfer of heat is considerably more intense than the molecular transfer of momentum and the thickness of the thermal boundary layer is greater than the thickness of the dynamic layer. In liquid metals heat is also transferred by the movement of electrons, which increases the influence of the transfer due to molecular activity. This electron contribution may be greater than the turbulent contribution (Reference 16).

The above reasons indicate that a different expression(s) is necessary to describe Nusselt number variation.

One of the best accumulation and analysis of experimental data on heat transfer coefficients for liquid metals is presented in Reference 19. Figure 42 of that reference shows the results of fifteen investigators and groups of investigators plotted as Nu versus the Peclet number, Pe. The following empirical equation was derived from this plot by the authors of Reference 19.

$$Nu = .625 \, Pe^{.4} \tag{5}$$

where

Pe = Peclet number of the fluid = (Re)(Pr).

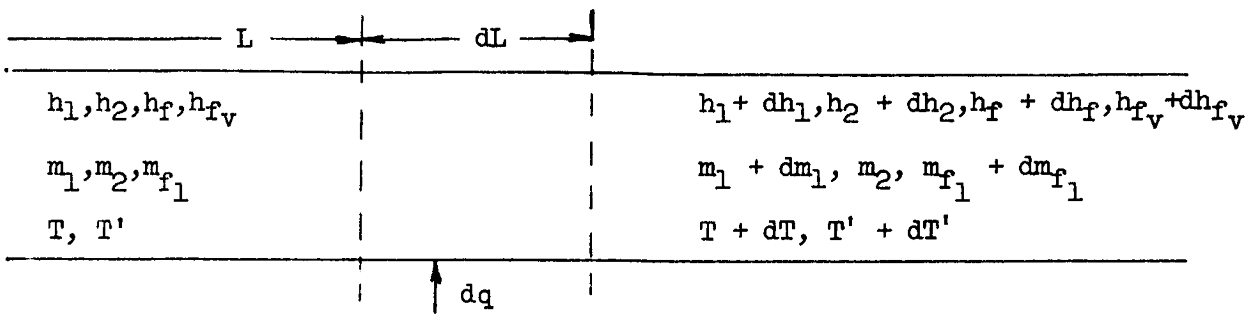
Although the authors state that the experimental evidence was insufficient to serve as a basis for any conclusion concerning liquid metal heat transfer in the laminar or transition flow region, the above equation shows fair agreement with the small amount of data available for those flow regimes. In the programs, Equation (5) is used for liquid metals for laminar, transition and turbulent flow.

3.1.5 Fuel Cell Radiator Heat Loss

When a mixture of vapors is forced through a tube whose surface temperature is below the dew point of one of the components, condensation of that component will occur. In the case under consideration, one of the gases (hydrogen) has a much lower saturation temperature than the other (water vapor); and, as such, the former is considered a noncondensable gas and the latter a condensable vapor. The condensation of the vapor causes a decrease in its partial pressure along the tube which results in a corresponding decrease in its dew point. If the total pressure of the mixture is high compared with the frictional

pressure drop along the tube, the effect of this pressure drop on the saturation temperature can be neglected.

The heat loss of the mixture is composed of the sensible heat loss of the noncondensable gas, the sensible heat loss of the vapor (including superheat), the sensible heat loss of the condensate and the latent heat of the vapor-to-liquid phase change. Examining a small section of a tube in which the mixture is flowing:



where the symbols:

T = saturation temperature
T' = superheat temperature

and subscripts:

1 = condensable vapor (steam)
2 = noncondensable gas (hydrogen)
f = condensate (water)

results in the following energy balance:

$$h_1 m_1 + h_2 m_2 + h_{f_1} m_{f_1} + dq = (m_1 + dm_1)(h_1 + dh_1) + m_2 (h_2 + dh_2) + (m_{f_1} + dm_{f_1})(h_{f_1} + dh_{f_1})$$

and $dq = m_2 h_2 + m_1 dh_1 + h_1 dm_1 + m_{f_1} dh_{f_1} + h_{f_1} dm_{f_1}$

By assuming both gas and vapor follow the perfect gas law and by employing Dalton's Law of partial pressures and Clapeyron's equation, the above energy balance can be written as:

$$dq = \left\{ m_2 c_2 \beta_2 + m_{o_1} c_{f_1} \beta_1 + m_2 \frac{R_2}{R_1 \left(\frac{P_m}{P_1} - 1 \right)} \left[\left(\frac{\partial h_{fv_1}}{\partial T} \right)_{Sat} + h_{fv_1}^2 \frac{T}{R_1 T^2} \frac{1}{\left(1 - \frac{P_1}{P} \right)} \right] \right\} dT \qquad (6)$$

where β_1 and β_2 are factors accounting for the sensible heat loss of the noncondensable gas and vapor mixture due to superheated inlet conditions (see Appendix A-5).

By plotting temperature and total pressure dependent portions of equation (6) for a hydrogen/water vapor mixture and curve fitting, the following expression was generated:

$$q = \left[m_2 c_2 \beta_2 + m_{o_1} c_{f_1} \beta_1 \right] (T_{in_{sat}} - T_{out})$$

$$+ 1770\, m_2 P_m^{-1.112} \quad (e^{.0237\, T_{in_{sat}}} - e^{.0237\, T_{out}}) \qquad (7)$$

where: q is in Btu/hr
m is in lb/min
c is in Btu/lb-°F
T is in °R
P is in psia

Equation (7) was then compared with a psychrometric chart for H_2-H_2O at 60 psia total pressure (intended operating pressure). An average error of 15% in the second term of equation (7) was noted for specific humidities from 0.5 to 3.0. This error is the result of small deviations of the components from perfect gas behavior and the magnification of this error caused by the steep slope of the saturation curve around the operating point. Consequently, the second term of equation (7) is multiplied by 1.15 in the programs to improve accuracy in the primary operating range.

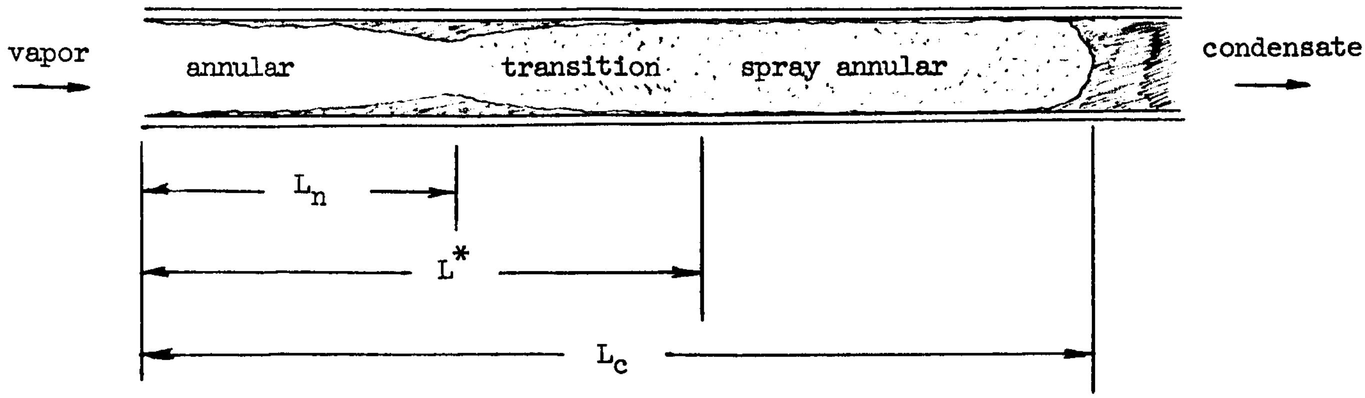
This modified equation is directly substituted into the fluid nodal point heat summation equations where T_{in} and T_{out} are the fluid boundary saturation temperatures of the section of tube under consideration.

The complete derivation of the equations presented in this section is contained in Appendix A-5.

3.2 Fluid Dynamics

3.2.1 Film Stability

The ability to accurately design and/or analyze a direct condenser-radiator requires insight into two-phase pressure drop phenomena which, in turn, requires a method(s) of flow regime prediction. As an example, consider the drawing shown on the following page:



This sketch shows all the flow regimes likely to occur in a through-flow space radiator-condenser. Intuitively, one can say that the pressure drop correlations for the various flow regimes are not identical and analysis and testing bears this out. The assumption of a single correlation may lead to gross errors in pressure drop prediction. It is, therefore, necessary to not only analyze methods for predicting two-phase pressure drop, but prior to this, to investigate methods of flow regime determination. Involved in this latter technology is the consideration of film stability since it is the instability of the film that trips the flow from pure annular to transition flow, and the growth rate of the waves which determines the transition length to fog flow.

Basically, two types of film instabilities may affect the performance of space condenser-radiators. The first is known as the Kelvin-Helmholtz (inertia and surface tension) instability and the second is the Schlichting-Tollmien (inertia and viscosity) instability. Both are characterized by the breakup of a wall-bound film and transition from annular to spray annular and/or fog flow (dispersed condensate). The present state-of-the-art is not sufficient to predict the point of neutral stability (start of transition flow) resulting from a combined effect of both of the above instabilities. Consequently, it will be assumed that each of the film instabilities act, and can be investigated, separately.

First, examine the Kelvin-Helmholtz phenomena. Reference 20 shows that the flow of a wall-bound film reaches neutral stability at a film Weber number defined as

$$W_f = \frac{U_2^2 \rho_f \delta}{g_s \sigma}$$

of 3.0. The film Weber number can also be expressed as

$$W_f = \left(\frac{D_o}{D} \right)^3 W_{v_o} X (1 - X) \left(\frac{\rho_v}{\rho_f} \right)^{1/2} \tag{8}$$

From equation (8) it can be seen that for certain values of initial vapor Weber

number, (W_{vo}), neutral stability will not be achieved for any value of quality, (X), and this type of instability will not occur.

For the Schlichting-Tollmien instability to cause a wall-bound fluid to reach neutral stability, Reference 20 shows that the film Reynold's number defined as

$$R_f = \frac{\delta \rho_f U_2}{\mu_f}$$

has to reach a value of 200. The film Reynold's number can also be expressed as:

$$R_f = \left(\frac{D_o}{2D}\right) R_{vo} \quad (1 - X) \frac{\mu_v}{\mu_f} \tag{9}$$

It can be seen from equation (9) that, as with the Kelvin-Helmholtz phenomena, the Schlichting-Tollmien instability may never occur in a condenser having certain inlet vapor Reynold's number values.

In the following analyses, it will be assumed that the neutral stability point will occur when the film Weber number reaches a value of 3.0 <u>or</u> when the film Reynold's number reaches a value of 200.

Once a neutral stability point, L_n, has been determined, it will be necessary to find L^*, the point at which the instability manifests itself as a change in flow regime from annular to spray annular and/or fog flow. To do this requires examination of the film growth rate. Starting with a wave growth and a wave propagation equation (Reference 21):

$$\frac{dB}{B} = \alpha_{ci} \frac{U_2}{\delta} \quad d\theta$$

$$dL = U_2 \left(\frac{C_R}{U_2} + 1 \right) d\theta + \theta \left(\frac{dC_R}{dU_2} + 1 \right) \quad dU_2$$

the following relationship for L^*/L_n can be derived (see Appendix B-2):

$$\ln\left(\frac{L^*}{L_n}\right) = \left[\ln\left(\frac{B^*}{B}\right)\right]\left[2 \alpha_{ci}\left(\frac{\rho_f}{\rho_v}\right)^{1/2} \frac{L_c}{D_o}\right]^{-1} \tag{10}$$

As an example, from Reference (22), $\ln\left(\frac{B^*}{B_n}\right) = 12$ when there are no external film disturbances. Also from References 20 and 23, $\alpha_{ci} = 0.02$ (Schlichting-Tollmien). Using water at 500°F $(\rho_f/\rho_v) = 30$, find L^*/L_n. Substituting into equation (10):

$L_c/D_o = 100$ $\qquad$ $L^*/L_n = 1.105$

$L_c/D_o = 200$ $\qquad$ $L^*/L_n = 1.0512$

For source of disturbances such as manifold turbulence, $\ln B^*/B_o < 12$ and L^*/L_n will be even closer to unity. Based on this example, the ratio L^*/L_n is assumed to equal unity in the programs.

The behavior of the fluid past the point of film breakup also requires investigation. Past this point, the liquid film builds up beyond the neutral stability limit to a value determined by a balance between the spray deposition rate and the entrainment rate as follows:

$$K_e\,(1 - X_e)\,G_m = \frac{B}{\delta}\,\alpha_{ci}\,U_2\,\frac{\rho_f}{2} \tag{11}$$

Equation (11) comes from Reference 24.

The growth rate factor, α_{ci}, is a function of the liquid film Reynold's number and should have a value in excess of R_{f_n} if $\alpha_{ci} > 0$.

Figure 5 sketched from Reference 21 shows the situation.

The state-of-the-art is insufficiently developed for accurate determination of the growth rate factor or the equilibrium film Reynold's number in the spray-annular flow regime, therefore, limiting situations should be taken into consideration. These are as follows:

1. All of the liquid phase is on the wall.

2. All of the liquid phase is entrained (fog or homogenous flow).

Based on Figure 5, the true solution is believed to be closer to limiting condition (2), that is, past the neutral point fog flow exists. This assumption is used in all the programs.

3.2.2 Two-Phase Pressure Drop

3.2.2.1 Single-Phase Friction Factors

For turbulent flow of a single-phase fluid, the friction factor depends on the Reynold's number and the relative roughness of the conduit surface. In laminar flow ($Re \leq 2000$) and transition ($2000 < Re < 4000$) flow the friction factor, however, depends only on the Reynold's number. (These Reynold's numbers used to separate flow regimes may vary somewhat depending on whose data is used, but these are the limits assumed in the programs.) If data for flow in smooth pipes in the turbulent regime ($Re \geq 4000$) is used, the following expressions for friction factors for flow in circular pipes can be derived by curve fitting of data presented in Reference 10.

For laminar flow ($Re \leq 2000$):

$$f = 64\ Re^{-1.0}$$

For transition flow ($2000 < Re < 4000$): (12)

$$f = .00277\ Re^{.322}$$

For turbulent flow ($Re \geq 4000$, smooth pipes):

$$f = .316\ Re^{-.25}$$

Equation (12) (known as the Moody friction factors) are used in the pressure drop calculations in all of the programs.

3.2.2.2 Frictional Pressure Drop Modulus, Φ_v^2

Based on the findings discussed in Section 3.2.1, the following flow patterns are possible in the radiator-condensers considered in this analysis: pure annular flow from tube inlet to point of neutral stability ($W_f \leq 3.0$ and $R_f \leq 200$) followed by fog or homogeneous flow, i.e., completely dispersed condensate ($W_f > 3.0$ or $R_f > 200$) up to end of the condenser. As mentioned in Section 3.2.1, the point of neutral film stability may never occur within the condensing length and pure annular flow may exist throughout the entire condenser.

In analyzing two-phase frictional pressure drop, it is convenient to introduce the Lockhart-Martinelli frictional pressure drop modulus, defined as:

$$\Phi_v^2 \equiv \frac{(dP/dL)_{TP}\ \text{(Two phase friction)}}{(dP/dL)_v\ \text{(Vapor only friction)}}$$

which is a measure of the influence of the liquid phase on the loss in pressure due to friction. With no liquid present, Φ_v^2 equals unity. The difficulty in solving for $(dP/dL)_{TP}$ lies in determining the proper Φ_v^2 consistent with the existing two-phase flow pattern. The value for $(dP/dL)_v$ can be readily determined from the bare tube vapor only relationship:

$$\left(\frac{dP}{dL}\right)_v = f_v\ \frac{\rho_v\ U_v^2}{2\ g_c}\ \frac{1}{D}$$

Based on the assumed two-phase flow regime model, the first flow pattern to be investigated is annular condensate flow with a pure vapor core. Within this section of condensing tube, four possible single phase flow regime combinations might exist: 1) laminar film and laminar core; 2) laminar film and turbulent core; 3) turbulent film and laminar core; 4) turbulent film and turbulent core. Data from Colburn (Reference 13), however, shows that the flow pattern of a condensate film propelled by vapor drag changes from laminar to turbulent for

values of film Reynold's numbers of approximately 200 which coincides with the assumed point of neutral film stability. Therefore, only expressions for Φ_v^2 for laminar film with either laminar or turbulent vapor core need be derived.

If a smooth liquid-vapor interface is assumed, the influence of the liquid phase on the loss of pressure in the annular region can be assumed to be due only to the reduction in diameter of the vapor passage.

For a laminar liquid film with laminar vapor core, Φ_v^2 can now be expressed as:

$$\Phi_v^2 = \left(\frac{D}{D_2}\right)^{4.0}$$

where the expression for $\left(\frac{D}{D_2}\right)$ is:

$$\left(\frac{D}{D_2}\right)^3 - 2\left(\frac{D}{D_2}\right)^2 + \frac{D}{D_2} - \left[\left(\frac{16}{f_v Re_v}\right)\left(\frac{m_f}{m_v}\right)\left(\frac{\mu_f}{\mu_v}\right)\left(\frac{\rho_v}{\rho_f}\right)\right] = 0 \quad (13)$$

An approximate solution of equation(13) for D/D_2 which is used in the program and which results in negligible error for the ranges of D/D_2 expected is:

$$\frac{D}{D_2} = 1 + \left[\left(\frac{16}{f_v Re_v}\right)\left(\frac{m_f}{m_v}\right)\left(\frac{\mu_f}{\mu_v}\right)\left(\frac{\rho_v}{\rho_f}\right)\right]^{1/2} \quad (14)$$

For a laminar film with turbulent vapor core Φ_v^2 is derived as:

$$\Phi_v^2 = \left(\frac{D}{D_2}\right)^{4.75}$$

where the expression for D/D_2 is:

$$\left(\frac{D}{D_2}\right)^{1.875} - \left(\frac{D}{D_2}\right)^{.875} - \left[\left(\frac{16}{f_v Re_v}\right)\left(\frac{m_f}{m_v}\right)\left(\frac{\mu_f}{\mu_v}\right)\left(\frac{\rho_v}{\rho_f}\right)\right]^{1/2} = 0 \quad (15)$$

An approximate solution of equation (16) for D/D_2 which is used in the programs and which results in negligible error for the ranges of D/D_2 expected is:

$$\frac{D}{D_2} = .5 + \left\{ .25 + \left[\left(\frac{16}{f_v Re_v}\right)\left(\frac{m_f}{m_v}\right)\left(\frac{\mu_f}{\mu_v}\right)\left(\frac{\rho_v}{\rho_f}\right)\right]^{.5} \right\}^{.5} \quad (16)$$

Deviations of equations (13) through (16) and errors resulting from the approximate solutions of equations (13) and (15) are presented in Appendix B-3. For the fog or homogeneous two-phase flow regime assumed to exist from point of neutral film stability to the end of the condensing section, the following expression for Φ_v^2 is applicable:

$$\Phi_v^2 = X^{-.75} \qquad (17)$$

This, as stated in Section 3.2.1, assumes negligible amounts of condensate on the tube wall. The derivation of equation (17) is presented in Appendix B-3.

The two-phase pressure moduli Φ_v^2, presented in this section are used in all the two-phase pressure drop calculations in the programs.

3.2.3 Secondary Pressure Losses

For the type of radiator-condensers considered in the computer programs, the total overall change in static pressure between inlet and outlet of the condenser be subdivided as follows:

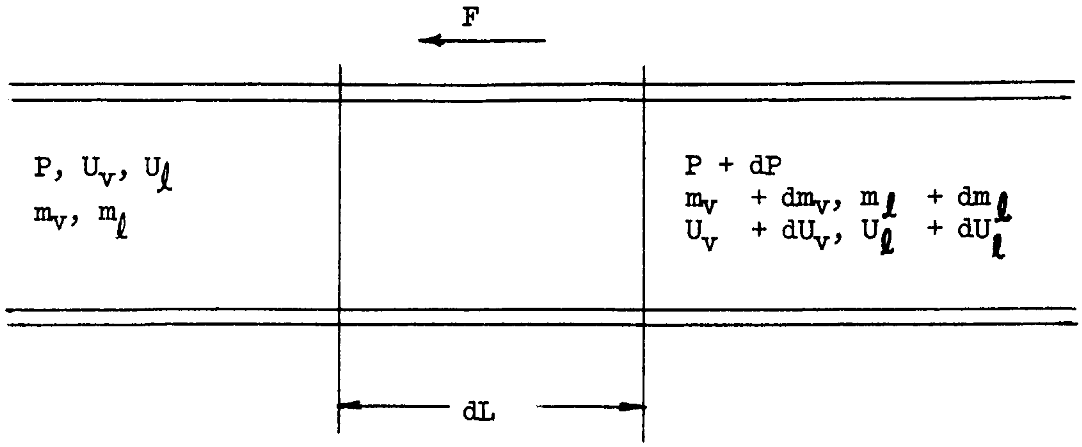
1. Inlet header frictional pressure loss.
2. Header-to-tube turning and entrance loss.
3. Two-phase frictional condensing pressure drop.
4. Pressure rise due to momentum recovery.
5. Frictional pressure loss in liquid subcooling leg (if applicable).
6. Tube to exit header turning loss.
7. Exit leader frictional pressure loss.

The two-phase frictional loss has been covered in Section 3.2.2.

All the inlet headers (and the outlet headers for the fuel cell and primary/secondary designs) should be designed for constant static pressure at the inlet of each tube. This is done by creating a momentum pressure recovery in the header between tube inlets equal to the header frictional pressure loss between the tubes. This momentum pressure recovery is accomplished by causing a velocity reduction along the header as the flow proceeds from the inlet to the outermost tube. (The momentum pressure recovery analysis is discussed later in this section.) This type of header, though, usually results in a design very close to that of one with a constant vapor velocity. This similarity, combined with the simplicity of a constant velocity header, prompted the use of the latter in the programs. The velocity used in the headers is the same as that in the inlet (or outlet) of the tubes. The frictional header losses, then, are calculated as though the average condition in the header exists throughout its length.

The entrance and exit losses from header to tube and tube to header are taken as one velocity head in the tube at that point. This assumption is based on data presented in Reference 25.

The momentum pressure recovery can be determined with the aid of the following sketch:



This sketch shows an incremental length of a condenser tube. Writing a momentum balance:

$$\Sigma F = (m_\ell + dm_\ell)(U_\ell + dU_\ell) + (m_v + dm_v)(U_v + dU_v) - m_\ell U_\ell - m_v U_v$$

$$\Sigma F = d(m_\ell U_\ell) + d(m_v U_v) = AdP$$

where now dP is the pressure change due to momentum change, then:

$$AdP = d(m\,U)_\ell + d(m\,U)_v$$

In the case of complete condensation (liquid/vapor interface):

$$\Delta P_{mom} = \Delta\left(\frac{\rho U^2}{g_c}\right)_v$$

Initially, at the condenser inlet, there is no liquid present ($X \approx 1.0$) and at the interface the liquid velocity is assumed zero; therefore, there is no change in liquid momentum. Furthermore, since there is no vapor momentum at the interface (zero velocity and flow rate) the momentum pressure recovery becomes:

$$\Delta P_{mom} = \left(\frac{\rho\, U_{in}^{\;2}}{g_c}\right)_v \qquad (18)$$

Since ΔP_{mom} has a positive sign, it indicates a pressure rise according to the sign convention of the sketch.

In the case of the primary/secondary design or the fuel cell condenser where no liquid/vapor interface bridges the tube, some assumption must be made with regard to the liquid velocity. In both cases, it is assumed that it is traveling at the same velocity as the vapor core. As a result, there is no momentum

recovery in the primary condenser since it has a constant vapor velocity throughout the tube and the loss in flow rate of the vapor is gained by the condensate.

In the case of the fuel cell radiator condenser:

$$A\Delta P = \Delta(m\,U)_\ell + \Delta(m\,U)_v$$
$$= \left[0 - m_o\,(1 - X)\,U_{out}\right] + \left[m_o\,U_{in} - X_e\,m_o\,U_{out}\right]$$

reducing:

$$\Delta P_{mom} = \frac{\rho_v\,U_{in}^{2}}{g_c} - \frac{\rho_v\,U_{in}\,U_{out}}{g_c} \tag{19}$$

These momentum pressure recovery terms, then, equations (18) and (19), are used in the appropriate pressure drop equations in the programs.

In all cases, frictional losses in the subcooler are assumed negligible due to the normally low velocities experienced here.

3.2.4 Flow Instability

In multiple-tube condensers two types of flow instability may occur: single tube instability and/or multiple tube instability. These instabilities, their causes and prevention, are discussed in the following paragraphs.

3.2.4.1 Single Tube Instability

This type of instability is caused by a low drag force exerted by the flowing vapor on the condensate. With flow in opposition to an external body force, this drag must overcome the external force with some excess to accelerate the condensate to the condenser outlet. In zero g operation, this drag must move the condensate along the tube wall at a rate fast enough to prevent bridging of the film, a symptom of instability. If this drag force is insufficient, the condensate flow rate in the tube will oscillate and eventually the tube may fill with condensate and system instability will result. Appendix B-4 examines the vapor velocity necessary to produce a sufficient drag force on the condensate in an acceleration field (flow against gravity). This analysis concludes with the equation:

$$n\left(\frac{6\,\mu_\ell\,m_\ell\,\rho_\ell}{\pi\,D\,g_c}\right)^{1/3} = \frac{f}{4}\,\rho_v\,\frac{U_v^{2}}{2\,g_c} + \frac{\Delta m_v U_v}{\pi\,D\,\Delta L g_c} \tag{20}$$

Equation (20) represents the minimum vapor velocity necessary to transport a condensate film against an acceleration force of n "g's". It can be seen that should n = 0, then $V_v = 0$ which is obviously not true. However, determination of the velocity, in this case, is beyond the present state-of-the-art and the best approach is to use some low value of n, say 0.05, in designing for zero g.

Equation (20) is contained in the programs and the value of n is solved for and is included in the outputs.

3.2.4.2 Multiple Tube Instability

This type of instability is also characterized by a filling or an emptying (of condensate) of a single tube in a parallel tube array but, in this case, is caused primarily by an insufficient frictional pressure loss in the condenser. Basically, this pressure loss has to be greater than the momentum pressure recovery and any static head which may be experienced in the condenser. Appendix B-5 is a discussion of this mode of instability. The appendix expresses the relationship:

$$\Delta P_f > \frac{2}{3} \frac{G_o^2}{\rho_v g_c} + \frac{L_v \rho_\ell n}{3} \tag{21}$$

which expresses the flow conditions necessary to insure parallel tube stability. Equation (21) is applicable to zero "g" (n = 0) but not to fuel cell radiators where complete condensation of the incoming mixture is not accomplished. In the latter case, the simpler form of equation (21), i.e., $\Delta P_s > 0$ is used. Both forms of equation (21)are included in the programs.

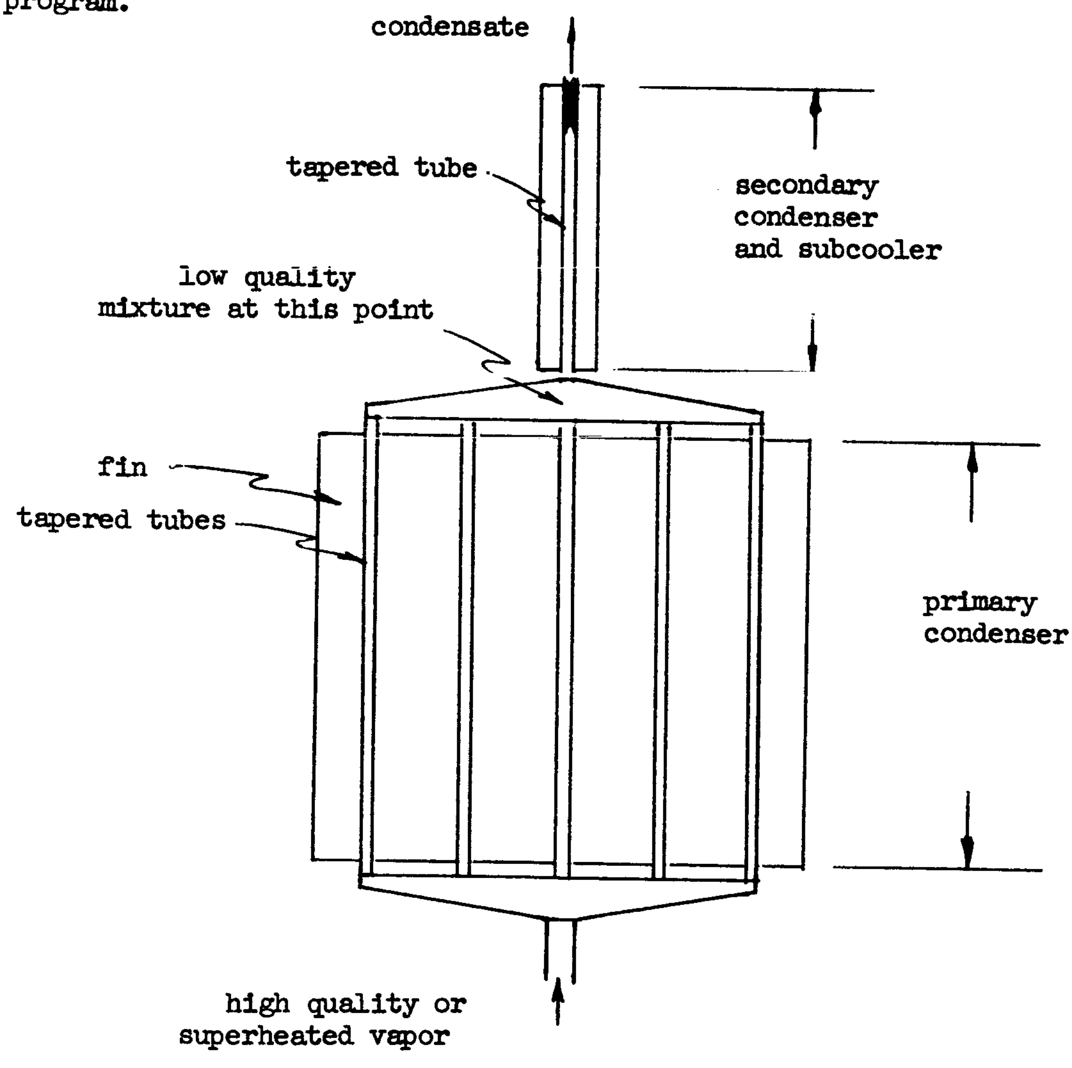
3.3 Primary/Secondary Concept

Geometrically, this type of radiator consists of a multiple tube radiator upstream of a single tube radiator. It has application to high ($\sim$ 1.0 g) acceleration fields where the gravitational direction is arbitrary to the extent that it may require condensation with flow in opposition to an external body force.

The multiple tube (or primary condenser) portion accepts a high quality of superheated mixture (from the turbine or compressor) and discharges a low quality mixture to the single tube (or secondary) condenser. The secondary condenser accepts this low quality vapor and delivers subcooled condensate to the pump or expansion valve. In both radiators, the tubes are tapered to maintain a high vapor velocity which is necessary for stable operation in "negative" g fields. This multiple/single tube configuration combines the lighter weight of the former with the higher stability of the latter. A sketch of the concept is shown on the following page.

There are many independent variables to consider in this design, the most significant of which is the outlet quality of the primary condenser. If a high outlet quality is designed into the radiator, the stability margin is increased but the weight is also driven up. The reverse is true in the case of a lower outlet quality. In the design program, this quality is taken as $12\frac{1}{2}\%$ based on previous optimization experience on the Sunflower I program (Reference 26). A detailed analysis of the concept as well as the basis of this and other assumptions is contained in Appendix B-6.

As part of the primary/secondary design computer program, a single tube subcooler is designed using the same fin as the secondary condenser. This subcooler design is performed for information only, since a subcooler of this type is not compatible with high negative acceleration field. Cavitation in the subcooler might occur as well as lowering of the pump or expansion valve inlet pressure (due to static head losses) below the minimum required for operation. In actuality, this subcooling should be accomplished indirectly in a short length to prevent this maloperation. It is important that this qualification be observed when using the results of the primary/secondary design program.



Primary/Secondary Concept

4.0 PROGRAMS DESCRIPTION

4.1 Design Programs

The basic method utilized in the design programs is to design a series of radiator condensers for all possible combinations of tube diameter, tube number, and fin width as instructed in the input. For instance, a portion of the input data is the minimum, maximum, and incremental tube number, tube diameter, and tube spacing to be considered. Although this input requires some knowledge of reasonable limits, this is not a severe restriction since experience usually provides this. In the event the user does not possess this experience, extremely wide limits with small increments may be used, but this may result in a higher computer rental cost. As an alternative, wide limits with large increments followed by a run with narrower limits (based on initial runs) and smaller increments may be used to conserve cost. In any case, the user chooses the radiator design best suited to his requirements (usually lightest weight) from the output data. This output data includes all the geometric characteristics of the radiator in addition to weight.

In addition to the inputs mentioned above, the construction material and fluid properties (except in the case of the H_2-H_2O fuel cell radiator) are required. These may be obtained, for all reasonable fluids and construction materials, from the Materials Manual, TRW ER-6756. Also required as inputs are the tube/fin and panel configuration (i.e., open sandwich, triform, etc.). The thermal environment must also be supplied as either a sink temperature or combinations of thermal and solar heat flux and absorptivity. And lastly, the flow conditions, i.e., flow rates, pressure drop, etc., must be known.

Optional inputs are:

1. Multiple sink temperature iteration. More than one sink temperature (or combinations of heat fluxes and absorptivities) may be inputed and the programs will design a series of radiators for each temperature (or set of combinations) and then automatically proceed to the next.

2. Minimum fin efficiency. A minimum fin efficiency of 0.4 is observed unless geometric limitations are specified. In the latter case, a minimum of 0.0 is used. In either case, a maximum of 1.0 is observed.

3. Maximum and minimum condenser length, condenser width, and fin thickness. These may be specified, but if none is, no limit is observed by the programs.

4. Tube wall thickness. This may be specified in the input, but if it is not, the tube wall will be calculated from meteoroid protection requirements which means that mission time and the desired probability of no meteoroid penetration must be given.

The programs use the results of the thermodynamic and fluid dynamic analyses of paragraphs 3.1 and 2.2 and Appendices A and B. In addition, the stability analyses of paragraph 3.2.4 and Appendix B are used to calculate the limiting acceleration field in which single and multiple tube stability can be maintained.

The basic operation of the design programs follows this sequence:

Input Data

↓

Tube Length Based on Allowable Pressure Drop

↓

Fin Thickness Based on Heat Rejection

↓

Condenser Geometry and Weight

In the calculation of heat rejection and pressure drop, the condenser is assumed to be broken into three longitudinal sections with constant conditions in each section. If a subcooler is present, it is thermally divided into two parts.

The following paragraphs treat each of the design programs in more detail.

4.1.1 Fuel Cell Design Program

Figure 6 is an information flow diagram of the fuel cell design program. In this type of radiator, a two component mixture of hydrogen gas and water vapor enters and a mixture of hydrogen gas, water vapor and water condensate is removed. As such, there is no liquid leg or subcooler to consider. For the purpose of heat transfer and pressure drop calculation, the condenser is divided into three equal longitudinal sections and the conditions at the center of each section are assumed to exist throughout that entire section.

The program operates in the following sequence:

1. The first combination of tube diameter, tube number and fin width is chosen, and the inlet and outlet flow conditions determined from the inputs. The sonic velocity check is made.

2. The inlet and outlet headers are designed assuming the same mixture velocity as at the inlet and outlet of the condenser tubes, respectively.

3. The header pressure drops and momentum pressure recovery are calculated and subtracted from the overall pressure drop allowance. This yields the two-phase frictional pressure drop.

4. Next, the multiple tube stability check is made.

5. The condenser length is calculated from the allowable two-phase pressure drop, assuming average flow conditions exist throughout the length of the tubes. This step requires calculation of core and film Reynolds numbers, film Weber number, friction factor, and two-phase pressure drop modulus.

6. At this point, the length limitation check (if any) is made, the single tube stability check is made, and the tube wall thickness is determined (if not an input) from meteoroid protection.

7. The total condenser width and area are calculated and the width limitation check (if any) and fin efficiency check are made.

8. The fin/tube and panel blockage factors are determined.

9. Using the inputs and calculated quantities applicable, including the condenser length determined from assuming average conditions, the fin thickness is calculated from convective heat transfer from fluid to tube wall, conductive heat transfer to and through the fins, and radiant heat transfer to space. This step involves the computer solution of a 21 x 21 matrix (three sections with one fluid temperature, two tube temperatures and four fin temperatures per section). Longitudinal conduction in the fins and tubes is taken into account. The thermal environment of space is also considered.

10. The fin thickness limitation check (if any) is made.

11. The flow conditions at the center of each section are determined and a new diameter which will satisfy the allowable two-phase pressure drop allowance is made. Again, this requires calculation of the same parameters (in each section, this time) as in step 5. This correction is usually very small and results in a tube diameter close to the input diameter.

12. Since this new diameter causes a change in the vulnerable tube area, a correct wall thickness from meteoroid protection requirements is calculated (again only if not specified in the input).

13. Finally, the total condenser area and weight are calculated and the program returns to the next combination of tube diameter, tube number, and fin width and repeats the process until the supply is exhausted.

4.1.2 Isothermal Design Program

Figure 7 is an information flow diagram of the isothermal design program. In this case, a superheated or high quality vapor enters the radiator and subcooled condensate is removed. For the purpose of heat transfer and pressure drop,

the condensing portion of the radiator is divided into three parts and the subcooler into two. No conduction between the condenser and subcooler is considered. (However, this heat flow path is taken into account in the isothermal performance analysis program.)

This program operates in the following sequence:

1. The first combination of tube diameter, tube number, and fin width is chosen and inlet flow conditions determined from the inputs.

2. The sonic velocity check is made.

3. The inlet header is designed, using the same velocity as at the inlet of the condensing tubes, and the header pressure drop calculated.

4. The header pressure drop and momentum pressure recovery are subtracted from the overall pressure drop allowance to yield the allowable two-phase pressure drop.

5. If the radiator panel geometry is a cone, an approximate subcooler-to-condenser length ratio is calculated (based on heat rejection rates and root temperatures) and from this, a fin width at the interface is determined.

6. By determining the flow conditions at the center of each of the condensing sections and assuming that condition exists throughout that section, the total condensing length is calculated from the allowable two-phase pressure drop. This requires the calculation (in each section) of core and film Reynold's numbers, film Weber number, friction factors, and two-phase pressure drop modulus.

7. The single tube and multiple tube stability checks are made.

8. An approximate subcooler length is determined.

9. An approximate tube wall thickness is calculated for meteoroid protection (if not fixed in the inputs) and the condenser width and radiation blockage factors are calculated.

10. The width limitation check (if required) and fin efficiency checks are made.

11. Using the inputs and calculated quantities applicable including the calculated condenser length, the fin thickness is determined from convective heat transfer from the fluid to tube wall and radiant heat transfer to space. This step involves the solution of a 7 x 7 matrix (a single section with two tube temperatures and four fin temperatures plus an additional total heat loss equation). Longitudinal conduction along the fins and tubes is not considered since the process is

essentially isothermal. The thermal environment of space is considered.

12. The fin thickness limitation check is made, if required.

13. A subcooler convection coefficient is calculated.

14. An exact subcooler length is determined. This requires the solution of a 14 x 14 matrix (two subcooler sections with one fluid temperature, two tube temperatures, and four fin temperatures per section).

15. An exact total length is calculated and the tube wall thickness is corrected (again, if not an input) for the small change in vulnerable area as a result of the difference in the corrected and approximate subcooler lengths and their effect on vulnerable area. The length limitation check is made, if required.

16. The total condenser area and weight are calculated and the program returns to the next combination of tube diameter, tube number, and fin width and repeats the process until the supply is exhausted.

4.1.3 Primary/Secondary Design Program

Figure 8 is an information flow diagram of the primary/secondary design program. This design is similar to the isothermal design in purpose, but the geometry is that of a single tube condenser-radiator downstream of a parallel tube one. The parallel tube portion (or primary) accepts a superheated or high quality mixture and discharges a low quality mixture. The single tube portion (or secondary) accepts the low quality mixture, completes the condensing, and rejects the heat of subcooling the condensate. This condenser radiator concept finds application where direct condensing against a high "g" field is required.

The program operates in the following sequence:

1. The first combination of tube diameter (at inlet to primary condenser), tube number, and fin width is chosen and the inlet and outlet flow conditions (of the primary condenser) determined. (In this program the outlet quality of the primary condenser is kept constant at 12.5%.) The sonic velocity check is made.

2. The inlet and outlet headers of the primary condenser are designed.

3. The header pressure losses and momentum recovery are calculated and subtracted from the overall drop listed in the inputs. Two thirds of this difference is allotted to the primary condenser (based on experience for optimized radiators). The remaining one-third is allotted to the secondary condenser.

4. Next, the primary condenser length is determined by assuming constant conditions in each of the three longitudinal sections of the condenser.

Again, this requires calculation of core and film Reynold's numbers, film Weber number, friction factor, and two-phase pressure drop modulus. The length limitation check is made. The gravitational capability is determined.

5. The secondary condenser length is determined from the remaining pressure drop assuming fog flow. This assumption is based on the high condensate flow rate which will cause a high film Reynold's number and resultant fog flow. Since multiple tube stability is not a problem in the secondary condenser, its fluid velocity may be half of that used in the primary condenser without a decrease in the stability margin.

6. The subcooler length is determined (assuming the same fin width and thickness as in the secondary condenser) from the sensible heat rejection requirement.

7. The tube wall thickness is calculated from the meteoroid protection requirement, unless listed in the input, and the primary condenser width and area calculated.

8. The width limitation check is made, if required, and the fin efficiency check is made.

9. The primary condenser fin thickness is then calculated based on the heat rejection requirements. This step involves the solution of a 7 x 7 tube/fin matrix (no longitudinal conduction). The fin thickness check is made.

10. Next, the fin width for the secondary condenser is calculated assuming an optimum weight fin ($\sim$ 57% efficient).

11. The secondary fin thickness is then calculated using the same matrix as in step 9.

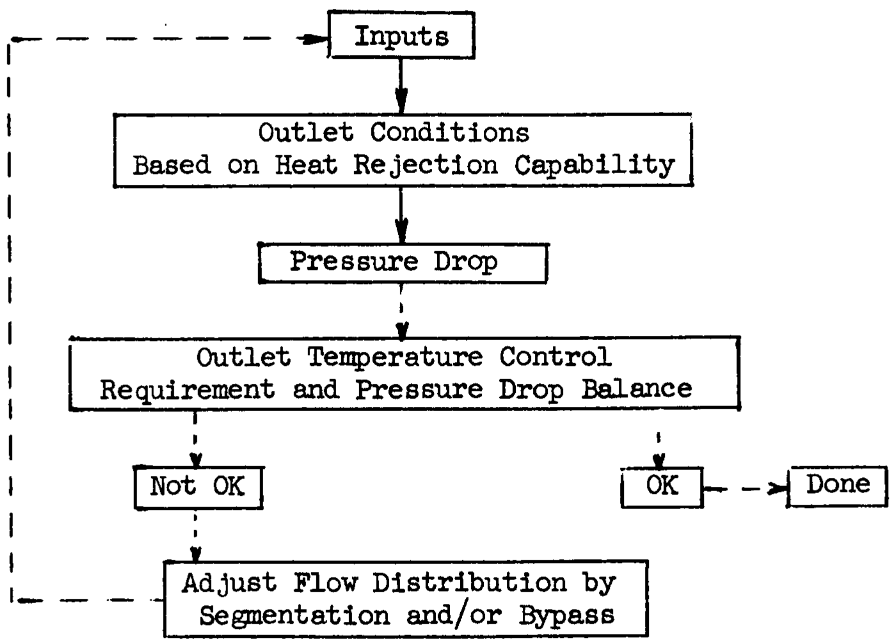
12. The total condenser area and weight are then calculated. The program returns to the next combination of tube diameter, tube number, and fin width and repeats the process until the supply is exhausted.

4.2 Performance Analysis Programs

These programs are intended to define the performance of an existing radiator under conditions other than those assumed in its design. As such, it is necessary that the complete geometry and fluid and material properties are known and the problem is to define the outlet conditions that will satisfy the heat transfer capability of the fins. (In the isothermal condenser, an additional problem of determining the pressure level exists.) Once the outlet condition is determined, the pressure drop is solved. Throughout the program the sonic velocity limitation and stability criteria discussed in paragraph 3.2.4 are observed.

An additional capability of being able to consider up to twelve simultaneous sink temperatures exists in the performance analysis programs. These sink temperatures (or combinations of heat fluxes and absorptivities) are needed as inputs. The programs then balance weight flow, pressure drop, and in the case of the isothermal condensers, condensing length, for each sink-temperature affected set of tubes, until the necessary equations are satisfied. Furthermore, the performance programs will automatically control to an outlet temperature, if desired, by segmentation and, in the case of the isothermal condensers, proportional bypass. Lastly, the isothermal case can consider constant inventory or constant pressure condensers.

The basic operation of the performance analysis programs follows this sequence:



---- if required

The same geometric breakdown as in the design programs, i.e., three sections in the condenser and two in the subcooler, if applicable, is used here. Longitudinal thermal conduction from the condenser to the subcooler is also considered in the analysis programs, again, if applicable.

The following paragraphs treat the two performance analysis programs in more detail.

4.2.1 Fuel Cell Performance Analysis Program

Figure 9 is an information flow diagram of the fuel cell performance analysis program

This program is limited to hydrogen gas/water vapor working mixtures and will

automatically segment to prevent freezing or to control an outlet mixture temperature, but does not consider proportional bypass of the radiator.

The program operates as follows: (In the following steps, it is assumed that more than one sink temperature is to be considered at a single time. In the event only a single sink is to be considered, some steps are obviously bypassed.):

1. The inlet saturation temperature is calculated and checked against the value of the outlet temperature to be met, if any. The inlet saturation temperature must be higher or the run is rejected and an explanation given.

2. The mixture velocity at the inlet of the tubes is calculated and compared with the sonic velocity. If the Mach number is greater than the maximum specified, the run is rejected and the Mach number noted.

3. The first sink temperature is chosen and compared with the inlet saturation temperature. If the sink temperature is higher, the outlet temperature of the radiator is assumed to be equal to the inlet saturation temperature, and the program proceeds to (5) below. This has the effect of assuming removal of the sensible heat of the mixture but no latent heat. If the sink is below the inlet saturation temperature, the program proceeds to the next step.

4. A temperature map of the radiator is generated in a 21 x 21 matrix (seven nodal points in each of three longitudinal sections). The solution yields the temperatures at the center of each of the three sections and the outlet temperature.

5. The pressure drop is calculated assuming constant conditions throughout each of the three sections (but different conditions in each section). This involves determination of film stability, flow regimes, and two-phase pressure drop moduli as in the design programs. This includes the case where the sink temperature is higher than the inlet saturation; one-third of the sensible heat is assumed to be lost in each section.

6. The pressure drops through each sink-temperature-affected set of tubes is then examined and the flow rates adjusted to produce equal pressure drops. (This is not done if only one sink temperature is to be considered.)

7. A check is made of the outlet temperature of each sink-temperature-affected set to see if any tubes are frozen. If they are, segments are automatically removed in the reverse order of the input listing until the freezing condition is alleviated (in the case of a segmentable radiator). If, with a frozen condition, the radiator cannot be segmented any further, or at all, the program stops and the situation

is described in an output statement.

8. Then the temperature resulting from mixing the outlet flow from all the tubes (assuming ideal mixing always on the saturation line) is calculated.

9. This mixture temperature is compared to the required mixture temperature, if given. If no mixture temperature is given, the program stops and the outputs printed. If the actual mixture temperature is lower than the required mixture temperature, segments are removed, if possible, in reverse order of the input listing, until the actual mixture temperature is above the required mixture temperature. The outputs from each segment combination are listed and the program stops. The last two combinations, then, will have the closest outlet mixture temperatures above and below the required temperature.

4.2.2 Isothermal Performance Analysis Program

Figure 10 is an information flow diagram of the isothermal performance analysis program.

This program can consider any fluid condensing isothermally and includes desuperheating and subcooling. The program will consider simultaneous multiple sink temperatures, automatic proportional bypass or segmentation to control the outlet temperature and constant inventory or pressure regulated condensers.

The program operates as follows:

1. An "average" sink temperature is found from those given.

2. If proportional bypass is to be employed, 25% of the flow is assumed to be bypassed at the start.

3. If a constant pressure condenser is used, an average condensing length is calculated assuming the "average" sink of step (1). If a constant inventory condenser is used, the average condensing length is specified in the inputs.

4. At this point, a check is made to be certain the condensing length of step (3) is less than the total length. If not, the run is stopped and the reason printed in the output.

5. Next, a temperature map of the "average" radiator is generated by the solution of a 33 x 33 matrix. This matrix describes the thermal behavior of the radiator including all longitudinal conduction, space thermal environment, and panel and tube/fin blockage factors. Five longitudinal sections are assumed, three in the condenser and two in the subcooler. Four fin and two tube nodal points per section are used in the condenser and four fin, two tube, and one fluid nodal point per section are used in the subcooler. One additional heat loss

equation makes up the 33 x 33 matrix. The solution of the matrix yields the outlet subcooling temperature and the condensing temperature, if it is not specified.

6. Next, the pressure drop is calculated, assuming, as in the other cases, constant flow conditions throughout each of the three longitudinal sections. As in the other cases, this pressure drop involves calculation of film conditions, flow regimes and two-phase pressure drop moduli as well as header, entrance and momentum pressure losses. The sonic velocity check is made, but the run is not stopped if the Mach number is greater than the maximum specified since further bypass or segmentation may rectify the situation.

7. At this point, if there is only one sink temperature and no segmentation or bypass is to be considered, the program is finished and the output printed. If there is more than one sink temperature, the pressure drop/mass flow/sink temperature/condensing length relationship of the average case is entered into a matrix which contains pressure drop, flow rate, condensing length, and sink temperature relationships for each sink-temperature-affected series of tubes. Solution of this matrix yields the individual values of the two dependent variables (condensing length, flow rate) for equal pressure drops and equal condensing temperatures in all the sink-temperature-affected series of tubes.

8. Each of these sets, then, is run through steps (2), (3), (4) and (5) for the <u>specific</u> rather than the <u>average</u> case.

9. If no outlet temperature is to be matched. this is the end of the simple multiple sink case, and the outputs are printed. If an outlet temperature is to be matched, the actual mixture temperature (obtained by mixing the outlets of all tubes plus the bypass, if any) is compared with the required mixture temperature.

10a. If proportional bypass is called for by the inputs, the bypass is adjusted to give this required temperature and the program returns to step (3). This is repeated until the outlet mixture temperature is within 1% of that called for in the input. At this point the outputs are printed.

10b. If segmentation is called for in the input, the present mixture temperature is compared to that required. If the former is higher, the program is stopped and the present performance printed in the outputs because no improvement can be made. If it is lower, segments are removed, one by one in the reverse order of the input listing (each time going back to step (1)), until the actual mixture temperature is above that required or no more segments are left. At this point, the result of the segment combinations examined are printed in the output and the program is completed. The last two combinations will provide the closest outlet mixture temperatures above and below that required.

5.0 RECOMMENDATIONS

(a) The programs developed herein do not consider single phase non-isothermal rejection of heat in space. This mode of waste heat radiation finds application in all indirect heat rejection systems as well as Brayton cycle power systems employing direct heat removal. A modification of the fuel cell programs developed on this contract would result in computer programs capable of this consideration at an economical cost.

(b) Expansion of the present programs to include system characteristics would be valuable. Since, in most systems, the components act as a feedback loop on the radiator, a radiator-condenser component analysis is limited in significance.

(c) Consideration of transient performance of radiators and/or radiator systems presents an accurate picture of the physical happening. It is recommended that these programs be expanded upon to include the transient effect either singly or in conjunction with (b) above.

6.0 DESIGN PROGRAMS

There are three direct radiator-condenser design programs: H_2-H_2O Fuel Cell Direct Radiator-Condenser, Isothermal Direct Radiator-Condenser with Subcooler, and Isothermal Primary-Secondary Direct Radiator-Condenser with Subcooler.

6.1 Independent Variables

Four independent variables have been chosen in the design programs. They are: 1) inside diameter of condenser tube at inlet, 2) number of tubes, 3) fin half-width, and 4) sink temperature or solar and thermal incident radiation. With other inputs specified, the design programs will investigate and design, if possible, a number of radiators equal to the number of possible combinations of 1), 2), 3) and 4) above.

Ranges of the inside diameter of condenser tube at inlet, tube number, and fin half-width are specified by giving a minimum value, a maximum value, and a value for an incremental step change. Different thermal environments are specified by different sink temperature values or different pairs of incident solar and incident thermal radiation.

The incident radiation to be entered in the input is the total thermal or solar energy intercepted by the total radiating area. In the case of a flat plate, for instance, the energy intercepted by one side of the radiator is added to that intercepted by the other and the sum is divided by the total (both sides) area. Sink temperatures and incident heat fluxes cannot be mixed for any one set of inputs; for example, if the user specifies the first environment with a given sink temperature, he cannot specify subsequent environments with incident radiation in the same set of inputs.

6.2 Geometric Configurations

Tube-fin configurations, panel configurations and working fluid class are included in the input through the code word PUNT. For the values for PUNT refer to Figure 11. For example, from Figure 11, a radiator having a closed sandwich, cruciform configuration and using water as the working fluid, the number for PUNT would be 3412. If the user requires a closed sandwich cylindrical or conical configuration, he must specify the "inner fin" thickness and density. In these cases, the first number of "PUNT" must be 2 and the program then treats the design as an open sandwich (the inner fin neither effects or affects heat transfer) but the weight of the inner fin is calculated.

If a conical panel configuration is desired, the cone diameters at inlet and exit have to be specified, thus removing one degree of freedom. The independent variable becoming dependent is fin half-width. No range of values for this variable (fin half-width) is, therefore, required. If a range of values is included, the program will ignore them.

If a segment of a cone is to be designed, equivalent values for DCMIN and DCMAJ must be solved for using:

DCMIN = $\frac{1}{\pi}$ times the arc length of the segment at the inlet

DCMAJ = $\frac{1}{\pi}$ times the arc length of the segment at the outlet

6.3 Optional Geometric Restrictions

Geometric restrictions can be imposed on overall width (circumference in case of cylinder), overall length (in primary/secondary radiator, maximum total length and maximum and minimum on primary condenser length), and total fin thickness (sum of both fins for closed sandwich, except in cylinder or cone where the fin thickness is of the "outer fin", only). If the user desires to impose one or more geometric restrictions, values have to be supplied for the minimum and maximum allowable values for the dimension(s). If a minimum value is desired, a maximum value must be also given, since the geometric limit tests are performed only if the maximum allowable dimension is non-zero. The program will design complete radiators for only those combinations of independent variables that cause the restricted dimension(s) to fall within the specified limits.

6.4 Diagnostic Tests

To obtain a complete radiator-condenser design, the programs insure that the following tests are passed:

Test No. 1 — Vapor velocity at tube inlet less than sonic velocity (single phase).

Test No. 2 — Pressure change due to friction is negative.

Test No. 3 — Overall length within specified limits (optional).

Test No. 4 — Overall width (or circumference) within specified limits (optional).

Test No. 5 — Fin thickness within specified limits (optional).

Test No. 6 — Approximate fin efficiency greater than .4 and less than 1.0 (if geometric restrictions are imposed the lower limit is set equal to zero).

Test No. 7 — Calculated gravitational capability greater than specified value (for primary/secondary program, only), (optional).

Test No. 8 — Secondary fin width greater than zero (primary/secondary condenser, only).

Test No. 9 Inlet water vapor saturation temperature higher than the required outlet saturation temperature (fuel cell design program, only).

Test No. 10 Convergence of matrices for temperature solution.

Failure to satisfy any of the above conditions will cause the program to select the next combination of independent variables.

If all, or a majority, of designs fail to pass one or more of the above tests, adjustments to the input values (excluding thermal environment and allowable pressure drop) may cause tests to be passed. These adjustments are contained in Figure 12.

6.5 H_2-H_2O Fuel Cell Radiator Design Program

6.5.1 Input Cards and Options

In order to use the H_2-H_2O fuel cell design program, a set (or sets) of input data cards must be prepared as follows (options under Sections 6.1, 6.2, 6.3 apply):

INPUT DATA CARD DESCRIPTION
FUEL CELL DESIGN PROGRAM

CARD NO.	COLUMN NOS.	SYMBOL	DESCRIPTION OR PARAMETER	UNITS	REQUIRED	OPTIONAL +
1	1-80		Identification card (any alphabetical or numerical combination)		X	
2	1-2 *		Number (n) of sink temperatures (TS) or pairs of incident solar (QIS) and thermal (QIT) heat fluxes to be considered without program restart (up to 20 values or combinations)		X	
3 to n + 2 (where n is defined on card 2)	1-10		When sink temperatures are given, value for TS; when incident fluxes are given, any negative number		X	
	11-20		When sink temperatures are given, zero; when incident fluxes are given, value for QIS		X	
	21-30		When sink temperatures are given, zero; when incident fluxes are given, value for QIT		X	
3 + n	1-10	MDG	flow rate of noncondensable gas, H_2	lb/min	X	
	11-20	MDVIN	flow rate of water vapor at condenser inlet	lb/min	X	
	21-30	PM	total pressure	psia	X	
	31-40	TIN	inlet temperature	^{o}R	X	
	41-50	TOUT	outlet fluid temperature of individual segment	^{o}R	X	
	51-60	DPTOT	overall static pressure loss	psi	X	
	61-70	KTH	thermal conductivity of tube material	BTU/hr-ft-^{o}F	X	
	71-80	KF	thermal conductivity of fin material	BTU/hr-ft-^{o}F	X	

* Right justify in field (all other inputs under decimal control).

\+ All cards are required; only entries are optional.

INPUT DATA CARD DESCRIPTION
FUEL CELL DESIGN PROGRAM (continued)

CARD NO.	COLUMN NOS.	SYMBOL	DESCRIPTION OR PARAMETER	UNITS	REQUIRED	OPTIONAL +
4 + n	1-10	RHOF	density of fin material	lb/ft^3	X	
	11-20	RHOT	density of tube material	lb/ft^3	X	
	21-30	RHOH	density of header material	lb/ft^3	X	
	31-40	TH	given header wall thickness	in	X	
	41-50	ET	emissivity of tube coating		X	
	51-60	EF	emissivity of fin coating		X	
	61-70	FSV	maximum allowable Mach number of vapor, only		X	
	71-80	DCMIN	diameter of conical panel at inlet	ft	Cone	
5 + n	1-10	DCMAJ	diameter of conical panel at outlet	ft	Cone	
	11-20	LCMIN	minimum allowable condensing length	ft		X
	21-30	LCMAX	maximum allowable condensing length	ft		X
	31-40	TIF	internal fin thickness, closed sandwich cone or cylinder	in		X
	41-50	RHOIF	density of internal fin material, closed sandwich cone or cylinder	lb/ft^3		X
	51-60	WMAX	maximum allowable total condenser width (in triform three times single panel width, etc.)	ft		X
	61-70	WMIN	minimum allowable total condenser width	ft		X
	71-80	TFMIN	minimum allowable fin thickness (both fins in a closed sandwich non-cone)	in		X

INPUT DATA CARD DESCRIPTION
FUEL CELL DESIGN PROGRAM (continued)

CARD NO.	COLUMN NOS.	SYMBOL	DESCRIPTION OR PARAMETER	UNITS	REQUIRED	OPTIONAL +
6 + n	1-10	TFMAX	maximum allowable TF fin thickness	in		X
	11-20	DIINO	smallest value of DIIN to be considered	in	X	
	21-30	DIINF	largest value of DIIN to be considered	in	X	
	31-40	DIIND	increment of DIIN to be considered	in	X	
	41-50	N O	minimum value of N to be considered		X	
	51-60	N F	maximum value of N to be considered		X	
	61-70	N D	increment of N to be considered		X	
	71-80	WINA O	smallest value of fin half-width to be considered	in	non-cone	
7 + n	1-10	WINA F	largest value of fin half-width to be considered	in	non-cone	
	11-20	WINA D	increment of fin half-width to be considered	in	non-cone	
	21-30	TTG	given tube wall thickness (will cause bypass of meteoroid protection requirement)	in		X
	31-40	TAU	mission time	days	If TTG=0	
	41-50	-LNPO (must be positive)	the negative of the natural log of the probability of no meteoroid puncture in TAU days		"	
	51-60	MEF	modulus of elasticity of fin material	psi	"	
	61-70	METH	modulus of elasticity of tube material	psi	"	
	71-80	ALPHS	solar absorptivity		If TS not given	
8 + n	1-10	ALPHT	thermal absorptivity		If TS not given	
9 + n	1-4 *	PUNT	(see figure 11)		X	

Cards 1 through (9 + n) may be repeated for different sets of inputs. The next identification card immediately follows the last card (PUNT) of the previous input set.

Radiator material properties should be evaluated near the saturation temperature. In most cases, the temperature value of the specified TOUT might be applicable. Most material properties do not vary greatly within the temperature range to be encountered, and an approximate value gives sufficient accuracy.

A typical input data sheet for the Fuel Cell Design Program is shown in Appendix C (Figure C-1).

6.5.2 Output Description

A typical set of outputs is shown in Appendix C (Figure C-2). A fixed input data block is followed by groups of outputs headed by a corresponding sink temperature value. For each combination of DIIN, N, WINA, a complete radiator design (consisting of 29 additional values) or the cause of a diagnostic test failure is given. The nomenclature used in the outputs is listed in the Nomenclature Section. However, several outputs require additional explanation.

DIINX

This is the actual value of the tube inlet inside diameter for the particular radiator design and should be the figure used. Its value is normally slightly different from that of DIIN.

WINX, WOUX

The values for the fin half-width at the inlet and exist headers are equal to each other and to WINA for all non-cone configurations. In a cone, WINA = 0 and WINX $\neq$ WOUX.

T10, T20, T30

These are saturation temperatures for the water vapor at nodes 10, 20 and 30, respectively.

MIF

Unless a value for the thickness (TIF) and density (RHOIF) of the "inner fin" (cylinder or cone with closed sandwich construction) is specified, this value is zero.

TTX

If TTX is negative (a result of the fins alone, providing sufficient meteoroid protections) the affected designs should be rerun with TTG specified based on strength requirements.

The output messages of Figure 13 (other than complete radiator designs) will appear after a particular combination of DIIN, N, WINA if a radiator cannot be designed. See Figure 12 for remedies.

6.6 Isothermal Radiator Design Program

6.6.1 Input Cards and Options

In order to use the isothermal radiator design program, a set (or sets) of input data cards must be prepared as follows (options under 6.1, 6.2, 6.3 apply):

INPUT DATA CARD DESCRIPTION
ISOTHERMAL DESIGN PROGRAM

CARD NO.	COLUMN NOS.	SYMBOL	DESCRIPTION OR PARAMETER	UNITS	REQUIRED	OPTIONAL +
1	1-80		Identification card (any alphabetical or numerical combination)		X	
2	1-2 *		Number (n) of sink temperatures (TS) or pairs of incident solar (QIS) and thermal (QIT) heat fluxes to be considered without program restart (up to 20 values or combinations)		X	
3 to n + 2 (where n is defined on card 2)	1-10		When sink temperatures are given, value for TS; when incident fluxes are given, any negative number		X	
	11-20		When sink temperatures are given, zero; when incident fluxes are given, value for QIS		X	
	21-30		When sink temperatures are given, zero; when incident fluxes are given, value for QIT		X	
3 + n	1-10	PC	average condensing pressure	psia	X	
	11-20	TC	average condensing temperature	$^{\circ}R$	X	
	21-30	MDT	total flow rate	lb/min	X	
	31-40	XIN	inlet quality		X	
	41-50	DPTOT	overall static pressure loss	psi	X	
	51-60	TOUT	outlet fluid temperature of individual segment	$^{\circ}R$	X	
	61-70	R	gas constant	$\frac{lb_f\,ft}{^{\circ}R\;lb_m}$	X	
	71-80	GAMMA	ratio of specific heats of vapor		X	

* Right justify in field (all other inputs under decimal control).

\+ All cards are required; only entries are optional.

INPUT DATA CARD DESCRIPTION
ISOTHERMAL DESIGN PROGRAM (continued)

CARD NO.	COLUMN NOS.	SYMBOL	DESCRIPTION OR PARAMETER	UNITS	REQUIRED	OPTIONAL +
4 + n	1-10	VISV	absolute viscosity of vapor	lb/ft-sec	X	
	11-20	VISL	absolute viscosity of condensate	lb/ft-sec	X	
	21-30	HFG	heat of vaporization of working fluid	BTU/lb	X	
	31-40	CL	specific heat of condensate	BTU/lb-^{o}F	X	
	41-50	RHOL	density of condensate	lb/ft^3	X	
	51-60	SUFT	liquid-vapor surface tension	lb/ft	X	
	61-70	KC	thermal conductivity of condensate	BTU/hr-ft-^{o}F	X	
	71-80	RHOT	density of tube material	lb/ft^3	X	
5 + n	1-10	RHOF	density of fin material	lb/ft^3	X	
	11-20	KTH	thermal conductivity of tube material	BTU/hr-ft-^{o}F	X	
	21-30	KF	thermal conductivity of fin material	BTU/hr-ft-^{o}F	X	
	31-40	RHOH	density of header material	lb/ft^3	X	
	41-50	TH	given header wall thickness	in	X	
	51-60	FSV	maximum allowable Mach number of vapor, only		X	
	61-70	ET	emissivity of tube coating		X	
	71-80	EF	emissivity of fin coating		X	
6 + n	1-10	CV	specific heat of vapor	BTU/lb-^{o}F	X	
	11-20	TIN	inlet temperature	^{o}R	X	
	21-30	TAU	mission time	days	If TTG=0	
	31-40	-LNPO (must be positive)	the negative of the natural log of the probability of no meteoroid puncture in TAU days		"	
	41-50	MEF	modulus of elasticity of fin material	psi	"	
	51-60	METH	modulus of elasticity of tube material	psi	"	
	61-70	TTG	given tube wall thickness (will cause by-pass of meteoroid protection requirement)	in		X
	71-80	ALPHS	solar absorptivity		If TS not given	

INPUT DATA CARD DESCRIPTION
ISOTHERMAL DESIGN PROGRAM (continued)

CARD NO.	COLUMN NOS.	SYMBOL	DESCRIPTION OR PARAMETER	UNITS	REQUIRED	OPTIONAL +
7 + n	1-10	ALPHT	thermal absorptivity		If TS not given	
	11-20	DCMIN	diameter of conical panel at inlet	ft	Cone	
	21-30	DCMAJ	diameter of conical panel at outlet	ft	Cone	
	31-40	LTMIN	minimum total length	ft		X
	41-50	LTMAX	maximum total condenser length	ft		X
	51-60	TIF	internal fin thickness, closed sandwich cone or cylinder	in		X
	61-70	RHOIF	density of internal fin material, closed sandwich cone or cylinder	lb/ft^3		X
	71-80	WMIN	minimum allowable total condenser width	ft		X
8 + n	1-10	WMAX	maximum allowable total condenser width (in triform three times single panel width, etc.)	ft		X
	11-20	TFMIN	minimum allowable fin thickness (both fins in a closed sandwich non-cone)	in		X
	21-30	TFMAX	maximum allowable TF fin thickness	in		X
	31-40	DMIN	minimum inside tube diameter to be considered	in	X	
	41-50	DMAX	maximum inside tube diameter to be considered	in	X	
	51-60	DDEL	increment of tube diameter to be considered	in	X	
	61-70	NMIN	minimum value of N to be considered		X	
	71-80	NMAX	maximum value of N to be considered		X	

INPUT DATA CARD DESCRIPTION
ISOTHERMAL DESIGN PROGRAM (continued)

CARD NO.	COLUMN NOS.	SYMBOL	DESCRIPTION OR PARAMETER	UNITS	REQUIRED	OPTIONAL +
9 + n	1-10	NDEL	increment of N to be considered		X	
	11-20	WIN MIN	minimum value of fin half-width to be considered	in	X	
	21-30	WIN MAX	maximum value of fin half-width to be considered	in	X	
	31-40	WIN DEL	increment of fin half-width to be considered	in	X	
10 + n	1-4 *	PUNT	(see figure 11)		X	

Cards 1 through (10 + n) may be repeated for different sets of inputs. The next identification card immediately follows the last card (PUNT) of the previous input set.

Radiator material and working fluid properties should be evaluated at the average condensing temperature (TC).

A typical input data sheet for the isothermal radiator design program is shown in Appendix C (Figure C-3).

6.6.2 Output Description

A typical set of outputs is shown in Appendix C (Figure C-4). A fixed input data block is followed by a statement showing the pump power consumed in the radiator condenser due to pressure drop. Groups of outputs headed by a corresponding sink temperature value follow. For each combination of DIIN, N, WINA a complete radiator design (consisting of 29 additional values) or the cause of a diagnostic test failure is given. The nomenclature used in the outputs is listed in the Nomenclature Section. However, several outputs require additional explanation.

WINXX, WOUXX

The values for the fin half-width at the inlet and exit leaders are equal to each other and to WINA for all non-cone configurations. In a cone WINA = 0 and WINXX≠WOUXX.

NUE, NPG

The smaller positive or larger negative value of the two gravitational capabilities governs. A negative value indicates that a gravitational force (based on NUE or NPG) in the direction of flow is necessary for stable operation.

MIF

Unless a value for the thickness (TIF) and density (RHOIF) of the "inner fin" (cylinder or cone with closed sandwich construction) is specified, this value is zero.

TTX

If TTX is negative (a result of the fins alone, providing sufficient meteoroid protection), the affected designs should be rerun with TTG specified based on strength requirements.

The output messages of Figure 14 (other than complete radiator designs) will appear after a particular combination of DIIN, N and WINA if a radiator cannot be designed. See Figure 12 for remedies.

6.7 Primary/Secondary Isothermal Radiator Design Program

6.7.1 Input Cards and Options

In order to use the primary/secondary radiator design program, a set (or sets) of input data cards must be prepared as follows (options under 6.1, 6.2, 6.3 apply):

INPUT DATA CARD DESCRIPTION
PRIMARY/SECONDARY DESIGN PROGRAM

CARD NO.	COLUMN NOS.	SYMBOL	DESCRIPTION OR PARAMETER	UNITS	REQUIRED	OPTIONAL +
1	1-80		Identification card (any alphabetical or numerical combination)		X	
2	1-2 *		Number (n) of sink temperatures (TS) or pairs of incident solar (QIS) and thermal (QIT) heat fluxes to be considered without program restart (up to 12 values or combinations)		X	
3 to n + 2 (where n is defined on card 2)	1-10		When sink temperatures are given, value for TS; when incident fluxes are given, any negative number		X	
	11-20		When sink temperatures are given, zero; when incident fluxes are given, value for QIS		X	
	21-30		When sink temperatures are given, zero; when incident fluxes are given, value for QIT		X	
3 + n	1-10	PC	average condensing pressure	psia	X	
	11-20	TC	average condensing temperature	^{o}R	X	
	21-30	MDT	total flow rate	lb/min	X	
	31-40	XIN	inlet quality		X	
	41-50	DPTOT	overall static pressure loss	psi	X	
	51-60	TOUT	outlet fluid temperature of individual segment	^{o}R	X	
	61-70	R	gas constant	$lb_f ft/^{o}R\ lb_m$	X	
	71-80	GAMMA	ratio of specific heats of vapor		X	

* Right justify in field (all other inputs under decimal control).

+ All cards are required; only entries are optional.

INPUT DATA CARD DESCRIPTION
PRIMARY/SECONDARY DESIGN PROGRAM (continued)

CARD NO.	COLUMN NOS.	SYMBOL	DESCRIPTION OR PARAMETER	UNITS	REQUIRED	OPTIONAL +
4 + n	1-10	VISV	absolute viscosity of vapor	lb/ft-sec	X	
	11-20	VISL	absolute viscosity of condensate	lb/ft-sec	X	
	21-30	HFG	heat of vaporization of working fluid	BTU/lb	X	
	31-40	CL	specific heat of condensate	BTU/lb-°F	X	
	41-50	RHOL	density of condensate	lb/ft^3	X	
	51-60	SUFT	liquid-vapor surface tension	lb/ft	X	
	61-70	KC	thermal conductivity of condensate	BTU/hr-ft-°F	X	
	71-80	RHOT	density of tube material	lb/ft^3	X	
5 + n	1-10	RHOF	density of fin material	lb/ft^3	X	
	11-20	KTH	thermal conductivity of tube material	BTU/hr-ft-°F	X	
	21-30	KF	thermal conductivity of fin material	BTU/hr-ft-°F	X	
	31-40	RHOH	density of header material	lb/ft^3	X	
	41-50	TH	given header wall thickness	in	X	
	51-60	FSV	maximum allowable Mach number of vapor, only		X	
	61-70	ET	emissivity of tube coating		X	
	71-80	EF	emissivity of fin coating		X	
6 + n	1-10	CV	specific heat of vapor	BTU/lb-°F	X	
	11-20	TIN	inlet temperature	°R	X	
	21-30	TAU	mission time	days	If TTG=0	
	31-40	-LNPO (must be positive)	the negative of the natural log of the probability of no meteoroid puncture in TAU days		"	
	41-50	MEF	modulus of elasticity of fin material	psi	"	
	51-60	METH	modulus of elasticity of tube material	psi	"	
	61-70	TTG	given tube wall thickness (will cause bypass of meteoroid protection requirement)	in		X
	71-80	NUEG	minimum gravitational capability	g's		X

INPUT DATA CARD DESCRIPTION
PRIMARY/SECONDARY DESIGN PROGRAM (continued)

CARD NO.	COLUMN NOS.	SYMBOL	DESCRIPTION OR PARAMETER	UNITS	REQUIRED	OPTIONAL +
7 + n	1-10	TFMIN	minimum allowable fin thickness (both fins in a closed sandwich non-cone)	in		X
	11-20	TFMAX	maximum allowable fin thickness	in		X
	21-30	LPMIN	minimum length of primary condenser	ft		X
	31-40	LPMAX	maximum length of primary condenser	ft		X
	41-50	WMIN	minimum allowable total condenser width	ft		X
	51-60	WMAX	maximum allowable total condenser width (in triform three times single panel width, etc.)	ft		X
	61-70	TIF	internal fin thickness, closed sandwich cone or cylinder	in		X
	71-80	RHOIF	density of internal fin material, closed sandwich cone or cylinder	lb/ft^3		X
8 + n	1-10	LTMAX	maximum total condenser length	ft		X
	11-20	ALPHS	solar absorptivity		If TS not given	
	21-30	ALPHT	thermal absorptivity		"	
	31-40	DIINP 0	minimum value of DIINP to be considered	in	X	
	41-50	DIINP F	maximum value of DIINP to be considered	in	X	
	51-60	DIINP D	increment of DIINP to be considered	in	X	
	61-70	N 0	minimum value of N to be considered		X	
	71-80	N F	maximum value of N to be considered		X	

INPUT DATA CARD DESCRIPTION
PRIMARY/SECONDARY DESIGN PROGRAM (continued)

CARD NO.	COLUMN NOS.	SYMBOL	DESCRIPTION OR PARAMETERS	UNITS	REQUIRED	OPTIONAL +
9 + n	1-10	N D	increment of N to be considered		X	
	11-20	WINA O	smallest value of fin half-width to be considered	in	X	
	21-30	WINA F	largest value of fin half-width to be considered	in	X	
	31-40	WINA D	increment of fin half-width to be considered	in	X	
10 + n	1-4 *	PUNT	(see figure 11)		X	

Cards 1 through (10 + n) may be repeated for different sets of inputs. The next identification card immediately follows the last card (PUNT) of the previous input set.

Radiator material and working fluid properties should be evaluated at the average condensing temperature (TC).

A typical input data sheet for the isothermal radiator design program is shown in Appendix C (Figure C-5).

6.7.2 Output Descriptions

A typical set of outputs is shown in Appendix C (Figure C-6). A fixed input data block is followed by a statement showing the pump power consumed in the radiator condenser due to pressure drop. Groups of outputs headed by a corresponding sink temperature value follow. For each combination of DIINP, N, WINA, a complete radiator design (consisting of 31 additional values) or the cause of a diagnostic test failure is given. The nomenclature used in the outputs is listed in the Nomenclature Section. However, several outputs require additional explanation.

MIF

Unless a value for the thickness (TIF) and density (RHOIF) of the "inner fin" (cylinder or cone with closed sandwich construction) is specified, this value is zero.

TTX

If TTX is negative (a result of the fins alone, providing sufficient meteoroid protections), the affected designs should be rerun with TTG specified based on strength requirements.

The output messages of Figure 15 (other than complete radiator designs) will appear after a particular combination of DIINP, N, WINA if a radiator cannot be designed. See Figure 12 for remedies.

7.0 PERFORMANCE ANALYSIS PROGRAMS

The two performance analysis programs are the H_2-H_2O Fuel Cell Direct Radiator Performance Analysis Program and the Isothermal Direct Radiator (with subcooler) Performance Analysis Program.

7.1 Thermal Environment Options

Again, as in the design programs, thermal environments can be specified in the form of sink temperature(s) or pair(s) of incident solar (including albedo) and incident thermal heat fluxes (see paragraph 6.1 for explanation of incident radiation). If heat fluxes are chosen, values for solar and thermal absorptivities (ALPHS, ALPHT) must be supplied. Up to twelve simultaneous sink temperatures (or pairs of heat fluxes) can be considered in one radiator analysis. Up to twelve sets of these simultaneous sink temperatures (or pairs of heat fluxes) can be analyzed consecutively for any one combination of geometric inputs. Within any set, temperatures and heat fluxes cannot be mixed. All sets used with one combination of geometric inputs must have an equal number of sink values.

Each sink temperature (or pair of incident radiation values) is assumed to affect equal numbers of tubes. Furthermore, if segmentation is to be considered to control outlet temperature (see paragraph 7.3.2), each segment is considered to "see" only one sink value.

7.2 Geometric Configurations

As in the design programs, the input value for PUNT is used to describe tube-fin and panel configurations and working fluid class. Figure 11 summarizes PUNT constituent values for specific geometries and fluid classes. (Note: A closed sandwich cone or cylinder must be treated as an open sandwich cone or cylinder; see Section 6.2.)

Segments within any radiator must have equal number of tubes and are treated as having individual inlet headers and individual outlet headers. (It is assumed that headers have been designed in accordance with the corresponding design program. (See paragraph 3.2.3.)

7.3 H_2-H_2O Fuel Cell Radiator Performance Analysis Program

7.3.1 Diagnostic Tests

The following tests are performed by the program:

1. The total hydrogen flow rate, MDG, and the total flow rate (water plus hydrogen), MDTG, are tested to see if both values are equal to zero. If so, the program will print the output statement:

   BOTH MDG AND MDTG ARE ZERO

and proceed to the next set of inputs, if available. This test insures that the mass flow input option has been observed properly (see paragraph 7.3.3).

2. The inlet saturation temperature is calculated and compared to the desired outlet mixture temperature, if specified. If the inlet saturation temperature is less than the outlet mixture temperature, the program will print the output statement:

   TINSA . . . LESS THAN TOUTM

   and proceed to the next set of inputs, if available.

3. If the inlet Mach number is higher than the maximum specified, the program will print the output statement:

   MACH NO TOO HIGH

   and proceed to the next set of inputs, if available.

4. If the 21 x 21 temperature matrix does not converge within 20 iterations, the program will print the output message:

   SLOW RATE OF CONVERGENCE

   and proceed to the next set of inputs, if available. This message should not normally appear unless an illogical set of inputs has been supplied.

5. If the outlet temperature of a segment is below freezing, (492°R), the program will store as possible output (if more than one segment is left) or will print (if only one segment is left) the statement:

   NS·S . . . FROZEN SEGMENT

   and will automatically segment, if possible, to alleviate the frozen condition. If no more segments are available, the program will proceed to the next set of inputs.

7.3.2 Outlet Mixture Temperature Control

In addition to the automatic freezing control of the individual segment outlet temperatures, the user has the option of controlling the mixed outlet temperature of the radiator-condenser by causing the removal of segments.

The user can effect segmentation by specifying a number of segment, (S), greater than one and by supplying a value for the radiator mixed outlet target temperature, (TOUTM).

If (TOUTM) is higher than the internally calculated inlet saturation temperature,

the program cannot analyze the radiator (see diagnostic test 2 under Section 7.3.1).

Since removal of individual segments causes a step change in the outlet mixture temperature, the program can only bracket the specified target temperature (providing the target temperature value falls between the outlet mixture temperature of the radiator with all segments working and the outlet mixture temperature of the radiator with one segment working).

In trying to prevent freezing, or in trying to bracket a specified outlet temperature, the program will remove segments in the reverse order in which their sink temperatures (or heat flux pairs) are listed in the input.

7.3.3 Input Cards and Options

In order to use the H_2-H_2O fuel cell performance analysis program, a set (or sets) of input data cards must be prepared as follows (options under sections 7.1, 7.2 and 7.3 apply):

INPUT DATA CARD DESCRIPTION
FUEL CELL PERFORMANCE PROGRAM

CARD NO.	COLUMN NOS.	SYMBOL	DESCRIPTION OR PARAMETER	UNITS	REQUIRED	OPTIONAL +
1	1-80		Identification card (any alphabetical or numerical combination)		X	
2	1-2 *		Number (n) of sets of simultaneous sink temperatures (or sets of pairs of incident solar and incident thermal heat fluxes) to be considered without program restart (up to 12 sets)		X	
3	1-2 *		Number (m) of simultaneous sink temperatures (or pairs of incident solar and incident thermal heat fluxes) in each set (up to 12 values)		X	
4,5,6, etc.,up to 3+m (where m is defined on card 3)	1-10		When sink temperatures (TS) are given, value for TS; when incident fluxes are given, any negative number		X	
	11-20		When sink temperatures are given, zero; when incident fluxes are given, value for QIS		X	
	21-30		When sink temperatures are given, zero; when incident fluxes are given, value for QIT		X	

Repeat cards 3 through 3 + m for each set of sink temperatures (or sets of pairs of incident fluxes) until all are entered. This will end with card number 2 + mn + n where n and m are defined on cards 2 and 3, respectively. The card in each succeeding set corresponding to card 3, i.e., (4 + m, 5 + 2m, 6 + 3m, etc.) must bear the same value as card 3.

\- -

* Right justify in field (all other inputs under decimal control).

\+ All cards are required; only entries are optional.

INPUT DATA CARD DESCRIPTION
FUEL CELL PERFORMANCE PROGRAM (continued)

CARD NO.	COLUMN NOS.	SYMBOL	DESCRIPTION OR PARAMETER	UNITS	REQUIRED	OPTIONAL +
3 + mn + n	1-10	N	total number of tubes		X	
	11-20	S	total number of segments available (in entire condenser)		X	
	21-30	DIIN	inside tube diameter	in	X	
	31-40	DOIN	outside tube diameter	in	X	
	41-50	WBARI	total condenser width at inlet	ft	X	
	51-60	WBARE	total condenser width at outlet (in triform, three times single panel width, etc.)	ft	X	
	61-70	TFIN	fin thickness at condenser inlet	in	X	
	71-80	TFOUT	fin thickness at condenser outlet	in	X	
4 + mn + n	1-10	TOUTM	mixed outlet target temperature	°R		X
	11-20	PM	total pressure	psia	X	
	21-30	ALPHS	solar absorptivity		If TS not given	
	31-40	ALPHT	thermal absorptivity		"	
	41-50	KTH	thermal conductivity of tube material	BTU/hr-ft-°F	X	
	51-60	KF	thermal conductivity of fin material	BTU/hr-ft-°F	X	
	61-70	ET	emissivity of tube coating		X	
	71-80	EF	emissivity of fin coating		X	
5 + mn + n	1-10	FSV	maximum allowable Mach number of vapor, only		X	
	11-20	LC	condensing length	ft	X	
	21-30	MDTG	total flow rate, $H_2 + H_2O$	lb/min	If MDG=0 &MDVIN=0	
	31-40	MDG	flow rate of noncondensable gas, H_2	lb/min	If MDTG=0 & SHIN=0	
	41-50	MDVIN	flow rate of water vapor at condenser inlet	lb/min	"	
	51-60	TIN	inlet temperature	°R	X	
	61-70	SHIN	inlet specific humidity		If MDG=0 & MDVIN=0	
6 + mn + n	1-4 *	PUNT	see figure 11		X	

Cards 1 through (6 + mn + n) may be repeated for different sets of inputs. The next identification card immediately follows the last card (PUNT) of the previous input set.

WBARI and WBARE are the total radiator panel widths at inlet and exit leader, respectively. They could be circumferences or arc lengths (cylinder and cone) or they could be the sum of the widths of the three or four individual panels of a triform or cruciform, respectively.

As noted on the input data card description, either the values for MDG and MDVIN or the values for MDTG and SHIN must be specified. If values appear in all four locations, MDG and MDVIN govern.

Radiator material properties should be evaluated near average expected saturation temperature.

A typical input data sheet for the fuel cell performance analysis program is shown in Appendix C (Figure C-7).

7.3.4 Output Description

A typical set of outputs is shown in Appendix C (Figure C-8).

The printout of the fixed input is followed either by a single output message as a result of a diagnostic test failure (see messages and causes for failures in Section 7.3.1), or it is followed by one or more blocks of outputs (a single block describes the performance of each individual segment) showing the results of the radiator analysis. Each block of output is preceded by a single line summarizing the total radiator performance with the segments printed in the block operating. One block of output results if no outlet mixture temperature is specified or if the required outlet mixture temperature is lower than the lowest possible radiator outlet temperature (all segments operating). If more than one block of output is shown, each successive block depicts the performance of the given radiator as segments are removed from operating (trying to match an outlet temperature or control freezing). If the required outlet temperature is within the range of possible outlet temperatures of the radiator, the last two blocks of output describe the performance of the radiator with different numbers of segments working and whose mixed outlet temperatures bracket, most closely, the required outlet temperature.

If it is physically impossible for the radiator to bracket the required outlet temperature, the program will print (S) number of output blocks and stop.

Another output combination results if freezing occurs with a large number of segments operating. The program will then print one or more of the following statements:

NS·S . . . FROZEN SEGMENT

followed by one or more blocks of output. The first block after the last "frozen segment" statement represents the performance of the radiator with the highest number of segments operating without freezing. If the mixed outlet temperature at this point is above the required, the program will stop. If it is not the program will continue to segment to bracket the outlet temperatures, if possible. Under no circumstances will the performance of a radiator be described which has any segment with an outlet temperature below $492^{o}R$.

Explanation of nomenclature used in outputs is listed in the Nomenclature section.

7.4 Isothermal Radiator Performance Analysis Program

7.4.1 Diagnostic Tests

The following diagnostic tests are performed by the program:

1. If the 7 x 7 condensing length (LCC) matrix does not converge within 20 iterations, the program will print the output message:

   20 CYCLES - - NOT CONVERGED - - LCC MATRIX

   and proceed to the next set of inputs.

2. The program subtracts the average condensing length solved for by the LCC matrix from the total radiator length in order to obtain the average subcooling length. If the average subcooler length is negative the program prints the output statement:

   STOP NEGATIVE LSC . . .

   and proceeds to the next set of inputs.

3. If the 33 x 33 temperature matrix does not converge within 20 iterations, the program will print the output message:

   20 CYCLES - - NOT CONVERGED - - T MATRIX

   and proceed to the next set of inputs. This message should not normally appear unless an illogical set of inputs has been supplied.

4. If the inlet Mach number is higher than the maximum specified, the program will cause output statements for the affected radiator or radiator segment to be accompanied by the statement:

   MACH . . . IS TOO HIGH - - WARNING

5. If, in the process of balancing pressure drops and mass flows in a multiple sink system, the condensing length of a segment is greater than the total radiator length, the program will print the statement:

   UNSTABLE LC GT LT

(where GT stands for greater than), print all available answers up to this point, and proceed to the next set of sink temperatures (or fluxes).

7.4.2 Constant Inventory or Constant Pressure Option

The user controls the condenser type by selecting a constant inventory or a constant pressure system. This is accomplished by specifying a certain combination for the values of three input variables. These are: desired average condensing length (LCG), estimated average condensing temperature (TCAPG) and desired average condensing temperature (TCG). If a constant inventory system is to be analyzed, the user must give a positive value to (LCG), a positive value to (TCAPG), and he must set TCG equal to zero. If a constant pressure system is to be analyzed, the user must give a positive value to (TCG) and he must set (TCAPG) and (LCG) both, equal to zero.

7.4.3 Mixed Outlet Temperature Control

The mixed outlet temperature of the condensate dowstream from the exit header of the radiator-condenser can be controlled by two methods: 1) segmentation (the blockage of flow through a radiator segment or segments), and 2) proportional bypass (the bypassing and mixing of vapor at inlet conditions with the liquid condensate from the condenser outlet).

Segmenting, bypassing, or no outlet temperature control is specified by the values assigned to the desired mixed outlet temperature (TMIXG) and the proportional bypass constant (PBP). If no outlet temperature control is desired, both (TMIXG) and (PBP) must be set equal to zero. For control by segmentation, the value for the desired outlet temperature must be assigned to (TMIXG) and PBP must be set equal to zero. For control by proportional bypass the value for the desired outlet temperature must be assigned to (TMIXG) and (PBP) must be set equal to 1.0.

Since removal of individual segments causes a step change in the outlet mixture temperature, the program can only bracket the specified target temperature (providing the target temperature value falls between the outlet mixture temperature of the radiator with all segments working and the outlet mixture temperature of the radiator with one segment working).

In proportional bypass the mixed outlet temperature (TMIXX) (after vapor addition) is calculated by the program to fall within 1.0% of the specified outlet mixture temperature (TMIXG).

7.4.4 Input Cards and Options

In order to use the Isothermal Performance Analysis Program, a set (or sets) of input data cards must be prepared as follows (options under 7.1, 7.2, 7.3 apply):

INPUT DATA CARD DESCRIPTION
ISOTHERMAL PERFORMANCE PROGRAM

CARD NO.	COLUMN NOS.	SYMBOL	DESCRIPTION OR PARAMETER	UNITS	REQUIRED	OPTIONAL +
1	1-80		Identification card (any alphabetical or numerical combination)		X	
2	1-2 *		Number (n) of sets of simultaneous sink temperatures (or sets of pairs of incident solar and incident thermal heat fluxes) to be considered without program restart (up to 12 sets)		X	
3	1-2 *		Number (m) of simultaneous sink temperatures (or pairs of incident solar and incident thermal heat fluxes) in each set (up to 12 values)		X	
4,5,6, etc., up to 3 + m (where m is defined on card 3)	1-10		When sink temperatures (TS) are given, value for TS; when incident fluxes are given, any negative number		X	
	11-20		When sink temperatures are given, zero; when incident fluxes are given, value for QIS		X	
	21-30		When sink temperatures are given, zero; when incident fluxes are given, value for QIT		X	

Repeat cards 3 through 3 + m for each set of sink temperatures (or sets of pairs of incident fluxes) until all are entered. This will end with card number 2 + mn + n where n and m are defined on cards 2 and 3, respectively. The card in each succeeding set corresponding to card 3, i.e., (4 + m, 5 + 2m, 6 + 3m, etc.) must bear the same value as card 3.

- -

* Right justify in field (all other inputs under decimal control).

\+ All cards are required; only entries are optional.

INPUT DATA CARD DESCRIPTION
ISOTHERMAL PERFORMANCE PROGRAM (continued)

CARD NO.	COLUMN NOS.	SYMBOL	DESCRIPTION OR PARAMETER	UNITS	REQUIRED	OPTIONAL +
3 + mn + n	1-10	N	total number of tubes		X	
	11-20	S	total number of segments available (in entire condenser)		X	
	21-30	DIIN	inside tube diameter	in	X	
	31-40	DOIN	outside tube diameter	in	X	
	41-50	WBARI	total condenser width at inlet	ft	X	
	51-60	WBARE	total condenser width at outlet (in triform, three times single panel width, etc.)	ft	X	
	61-70	TFIN	fin thickness at condenser inlet	in	X	
	71-80	TFOUT	fin thickness at condenser outlet	in	X	
4 + mn + n	1-10	LT	total condenser length (including subcooler)	ft	X	
	11-20	LCG	specified average condensing length	ft	If TCG=0	
	21-30	HFG	heat of vaporization of working fluid	BTU/lb	X	
	31-40	M	working fluid molecular weight	lb_m/lb_{mole}	X	
	41-50	R	gas constant	$lb_f ft/{}^\circ R\ lb_m$	X	
	51-60	PIR	reference saturation pressure (see paragraph 7.4.4)	psia	X	
	61-70	TIR	reference saturation temperature (at PIR) (see paragraph 7.4.4)	°R	X	
	71-80	KC	thermal conductivity of condensate	BTU/hr-ft-°F	X	

INPUT DATA CARD DESCRIPTION
ISOTHERMAL PERFORMANCE PROGRAM (continued)

CARD NO.	COLUMN NOS.	SYMBOL	DESCRIPTION OR PARAMETER	UNITS	REQUIRED	OPTIONAL +
5 + mn + n	1-10	RHOL	density of condensate	lb/ft^3	X	
	11-20	VISL	absolute viscosity of condensate	lb/ft-sec	X	
	21-30	CL	specific heat of condensate	BTU/lb-°F	X	
	31-40	SUFT	liquid-vapor surface tension	lb/ft	X	
	41-50	CV	specific heat of vapor	BTU/lb-°F	X	
	51-60	VISV	absolute viscosity of vapor	lb/ft-sec	X	
	61-70	GAMMA	ratio of specific heats of vapor		X	
	71-80	ALPHS	solar absorptivity		If TS not given	
6 + mn + n	1-10	ALPHT	thermal absorptivity		If TS not given	
	11-20	KTH	thermal conductivity of tube material	BTU/hr-ft-°F	X	
	21-30	KF	thermal conductivity of fin material	BTU/hr-ft-°F	X	
	31-40	ET	emissivity of tube coating		X	
	41-50	EF	emissivity of fin coating		X	
	51-60	FSV	maximum allowable Mach number of vapor, only		X	
	61-70	NOS	number of different sink temperature values		X	
	71-80	PBP	proportional bypass code (see paragraph 7.4.2)			X
7 + mn + n	1-10	MDT	total flow rate	lb/min	X	
	11-20	XIN	inlet quality		X	
	21-30	TCG	specified average condensing temperature	°R	If LCG=0	
	31-40	TCAPG	approximate condensing temperature	°R	If TCG=0	
	41-50	TIMTC	inlet superheat	°R		X
	51-60	TMIXG	target outlet mixture temperature			X
8 + mn + n	1-4 *	PUNT	(see figure 11)		X	

Cards 1 through (8 + mn + n) may be repeated for different sets of inputs. The next identification card immediately follows the last card (PUNT) of the previous input set.

WBARI and WBARE are the total radiator panel widths at inlet and exit header, respectively. They could be circumferences or arc lengths (cylinder and cone) or they could be the sum of the widths of the three or four individual panels of a triform or cruciform, respectively.

PIR and TIR are reference saturation pressure and temperature of the working fluid to be used in the Clausius Clapeyron equation (see equation A-33, Appendix A). They can be taken anywhere on the saturation line; however, due to the nature of the equation, more accuracy is obtained if the values are taken close to expected operating conditions. It should be noted that these are reference values only and do not limit the condenser operation to these levels.

NOS is the number of different sink temperature (or pairs of fluxes) values. It is equal to or less than S (total number of segments). For example, if all of twelve sink temperature values are equal to each other, NOS = 1.0; however, for twelve non-equal sink values, NOS = 12.0.

Sections 7.4.2 and 7.4.3 discuss the special attention that has to be paid to LCG, TCG, TCAPG (constant inventory - constant pressure option) and PBP, TMIXG (outlet mixture temperature control option), respectively.

Average fluid and radiator material properties should be taken at TCG or TCAPG, whichever is given. Most properties vary only slightly over typical temperature ranges that can be expected in any one isothermal radiator condenser and, therefore, taking the desired values at the above temperature should introduce negligible error.

A typical input data sample sheet is shown in Appendix C (Figure C-9).

7.4.5 Output Description

Typical sets of outputs are shown in Appendix C (Figure C-10).

Outputs for radiator-condenser performance analyses will be discussed according to types of outlet mixture temperature control: 1) no outlet mixture temperature control, 2) outlet mixture temperature control by segmentation, and 3) outlet mixture temperature control by proportional bypass. In all three types a block of fixed input data precedes all output groupings.

Explanation of nomenclature used in outputs is listed in the Nomenclature Section.

7.4.5.1 Outputs for "No Outlet Temperature Control" Cases

Unless any one of the output messages discussed in Section 7.4.1 appears, the block of fixed input data for a performance analysis of a radiator without

outlet mixture temperature control will be followed by one group of output sets. The group of output sets is headed by a statement giving the average sink temperature value. This statement is followed by sets of outputs titled "SET NO. 0", followed by "SET NO. 1", "SET NO. 2", "SET NO. 3", up to "SET NO. S",(where S is the total number of radiator segments). Outputs under "SET NO. 0" are for an average segment of the radiator-condenser (using average condensing length, average sink temperature and average mass flow). Set No. 1 through Set No. (S) show outputs applicable only to the respective individual segment of the radiator (differences in the output values of the sets are the net result of the differences in their thermal environments). Set No. (S) is followed by a line of outputs applicable to the overall radiator-condenser performance. For a no-outlet-temperature-control case, (THETA) and (TMIXX) are always zero. (DPTM) will be shown as zero for a single sink temperature value (NOS = 1.0) and the value (DPTOT) should be used for pressure drop. (TCM) will also be shown as zero for a single sink temperature value (NOS = 1) and for constant pressure cases, regardless of the number of sink values. An average of the TC's shown should be used in these cases.

For a case where (S) = 1.0 (only one segment) or (NOS) = 1.0 (all sinks equal), Set No. 0 will be the only output set (followed by overall radiator values). For a one segment radiator, Set No. 0 performance values describe total radiator performance. For the multi-segment, equal sink case, Set No. 0 shows values typical for each of the segments.

If Set No. 1 through Set No. (S) occur, it should be noted that (excluding Set No. 0):

1. The smallest single value of all NUE's and NPG's is the governing overall gravitational capability (any negative value means a gravitational force in flow direction is required).

2. The small deviations between individual TC's and their deviation from TCG (if applicable) are due to specified limits of matrix convergence.

3. Deviation between individual DPTOT values are a result of TC deviations explained above.

A partially completed typical output block followed by one of the messages discussed in Section 7.4.1 is also a possible output combination.

7.4.5.2 Outputs for "Outlet Temperature Control by Segmentation" Cases

Unless the printout of the fixed input is immediately followed by one of the messages discussed in Section 7.4.1, one or more typical output groups headed by an average sink temperature (based on the number of operating segments within the group) will follow. It should be noted that diagnostic test failure messages can terminate the output within or after any group. Each output group consists of output sets showing values for an average segment case followed by sets showing applicable output values of each individual operating segment. The last line in each group lists outputs applicable to the overall working

postion of the radiator-condenser. Values for (THETA) and (TMIXX) are always zero. (DPTM) and (TCM) are zero for a multi-segment radiator with equal sink temperatures. (TCM) will also be zero for a constant pressure case. (DPTOT) and the average(TC)should be used, respectively.

One group of output sets results if the required outlet mixture temperature is lower than the lowest possible radiator outlet temperature (all segments operating). If more than one group of output is shown, each successive group depicts the performance of the given radiator as segments are removed from operation (trying to match an outlet temperature). If the required outlet temperature is within the range of possible outlet temperatures of the radiator, the last two groups of output describe the performance of the radiator with different numbers of segments working and whose mixed outlet temperatures bracket, most closely, the required outlet temperature.

If it is physically impossible for the radiator to bracket the required outlet temperature, the program will print (S) number of output groups and stop.

Successive output groups for a multi-segment radiator with equal sink temperatures will contain only Set No. 0 which will be typical of those segments in operation at that time.

The same interpretations as listed in points 1 through 3 in Section 7.4.5.1 apply to each group in the output for a case involving outlet mixture temperature control by segmentation.

7.4.5.3 Outputs for "Outlet Mixture Temperature Control by Proportional Bypass" Case

Output groups and set description are identical to those used to describe the special outlet temperature control cases in Sections 7.4.5.1 and 7.4.5.2 with the following exceptions:

1. Each group of output has an equal number of sets (Set No. 0 through Set No. (S)).
2. The average sink temperature is only listed once (before first group).
3. THETA and TMIXX are non-zero and applicable.
4. The program will continue to vary(THETA)and calculate output groups until the value for(TMIXX)is within 1.0% of the specified value for (TMIXG)or the program is stopped due to a diagnostic test failure.

The (THETA) value listed in a group (other than the last group) is calculated based on the values of (TOMIX) and (TMIXX) in that group but is used in calculating the following group of outputs; therefore, the initial value of THETA is not shown in the first group.

Should the program satisfy the outlet mixture target temperature within the 1.0% limit, the last two groups of output will have equal THETA's with the last group describing the performance with this(THETA.)

Enroute to the final answer (last output group) (THETA) may oscillate and become negative. However, for a true answer the final(THETA)must be positive. If this is not so, an unrealistic target temperature (TMIXG) was chosen for the particular operating conditions. The output groups preceding the final group (desired answers) are printed for information only and may contain unrealistic answers.

EXAMPLES OF SPACE RADIATOR TYPES

HEAT REJECTION MODE	TEMPERATURE LEVEL	
	HIGH	LOW
Two-Phase, Single Component, Isothermal	Liquid Metal Rankine Cycle Power Systems with Direct Condenser-Radiator	Non-Metal Rankine Power Systems with Direct Condenser-Radiator Environmental Control Systems with Direct Condenser-Radiator
Single Phase, Non-Isothermal	Liquid Metal Rankine Cycle Power Systems with Indirect Radiator	Environmental Control Systems with Indirect Radiator Fuel Cell System with Indirect Radiator Non-Metal Rankine Power Systems with Indirect Radiator Brayton Cycle Power Systems with Direct or Indirect Radiator
Two-Phase, Two-Component, Non-Isothermal		Fuel Cell System with Direct Radiator

Figure 1

SIMPLIFIED SCHEMATICS OF SYSTEMS
EMPLOYING A DIRECT CONDENSER-RADIATOR

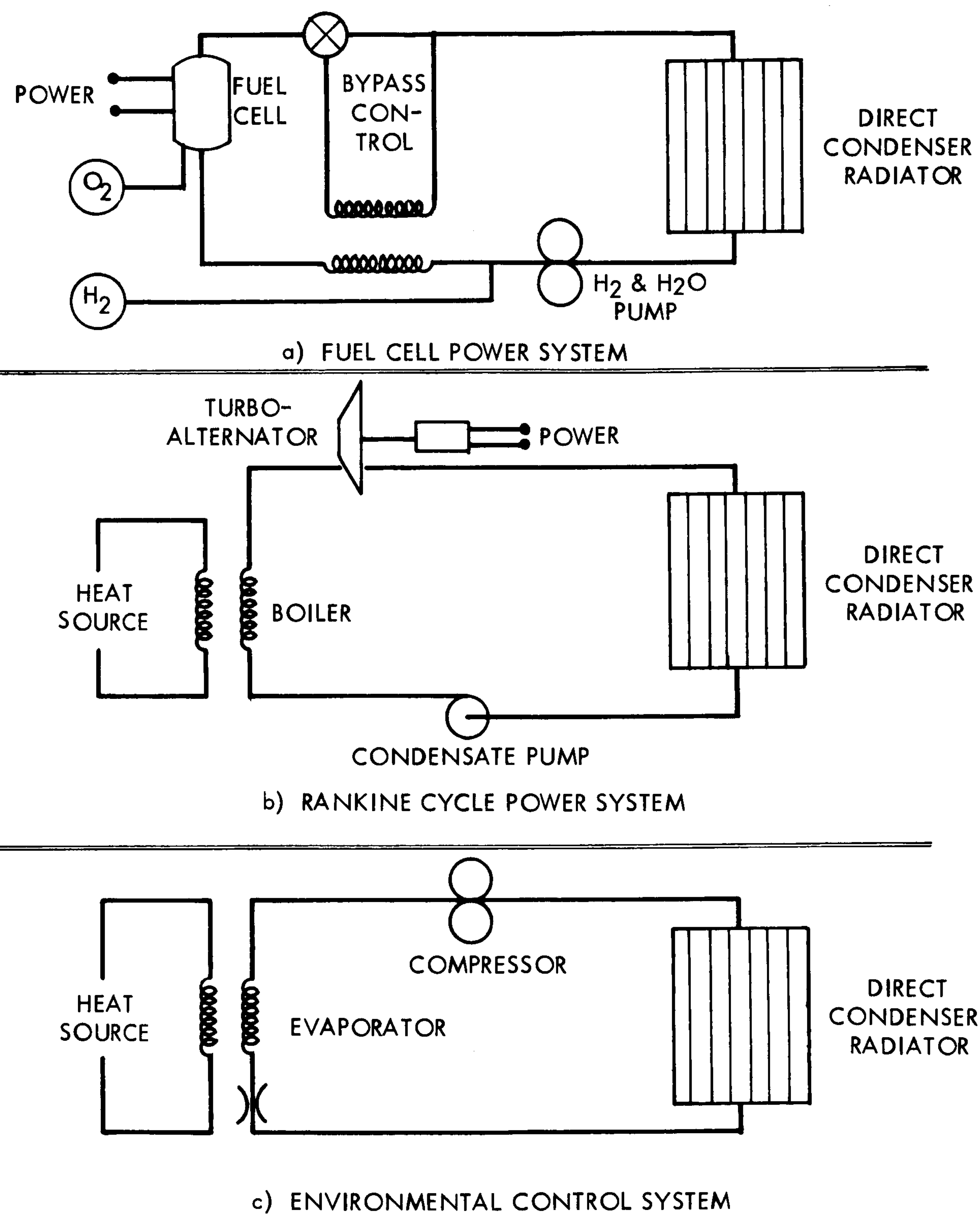


Figure 2

APPLICATION OF PANEL CONFIGURATIONS TO THE COMPUTER PROGRAMS

PROGRAM	PANEL TYPES					
	FLAT PLATE	TRIFORM	CRUCIFORM	CYLINDER	CONE: CONSTANT FIN THICKNESS	CONE: TAPERED FIN THICKNESS
Fuel Cell						
Design	X	X	X	X	X	
Analysis	X	X	X	X	X	X
Isothermal						
Design	X	X	X	X	X	
Analysis	X	X	X	X	X	X
Pri/Sec Design	X	X	X	X		

Figure 3

FIN-TUBE NODAL POINT LOCATIONS

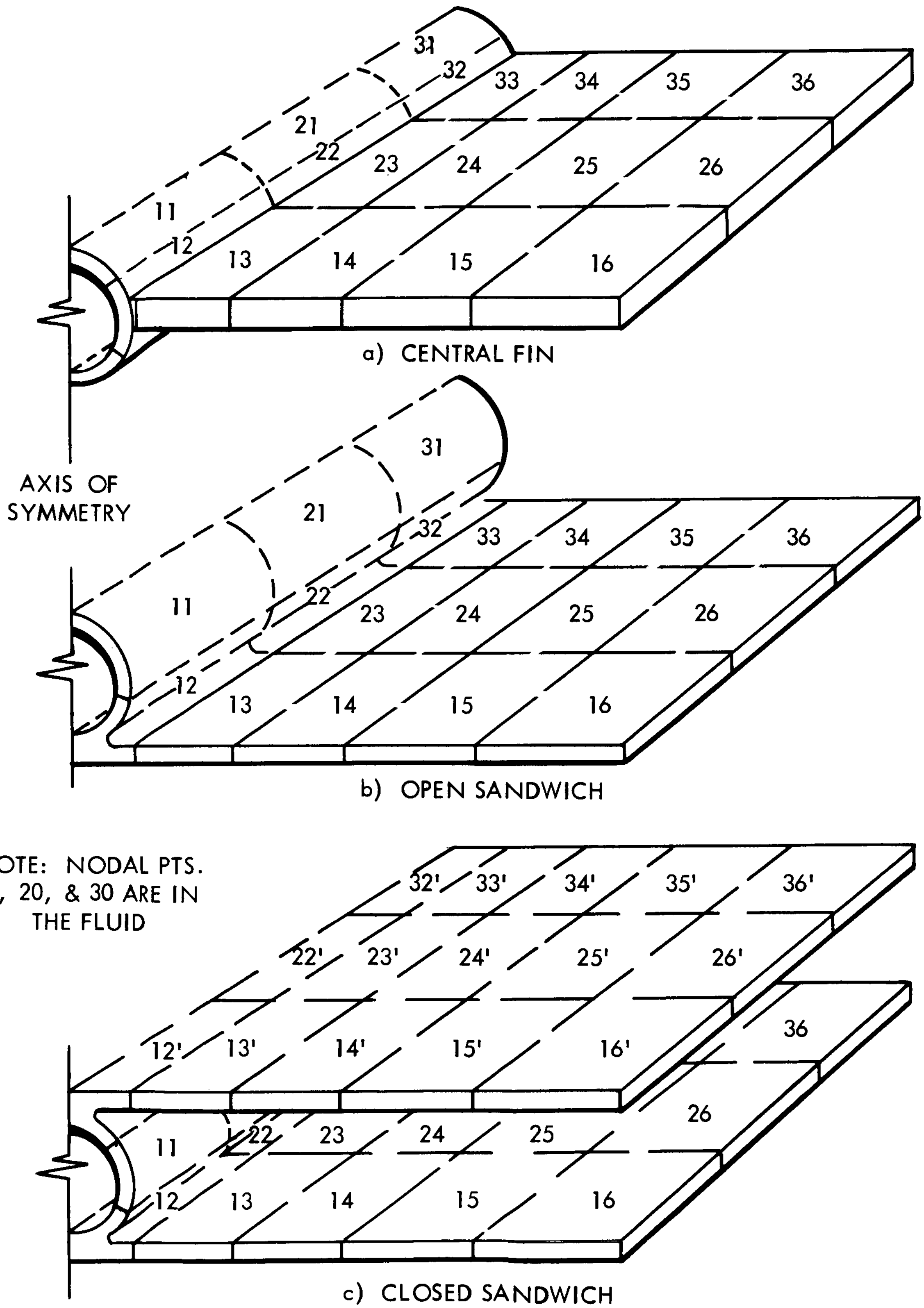


Figure 4

EFFECT OF ENTRAINMENT ON FILM FLOW RATE

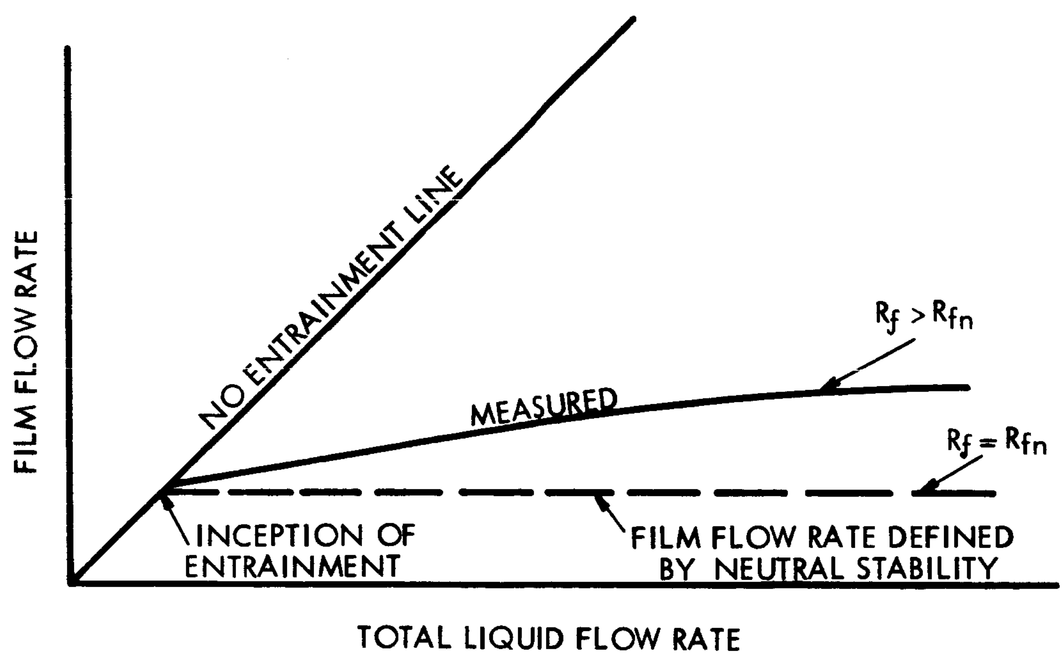


Figure 5

FUEL-CELL DESIGN PROGRAM
INFORMATION FLOW CHART

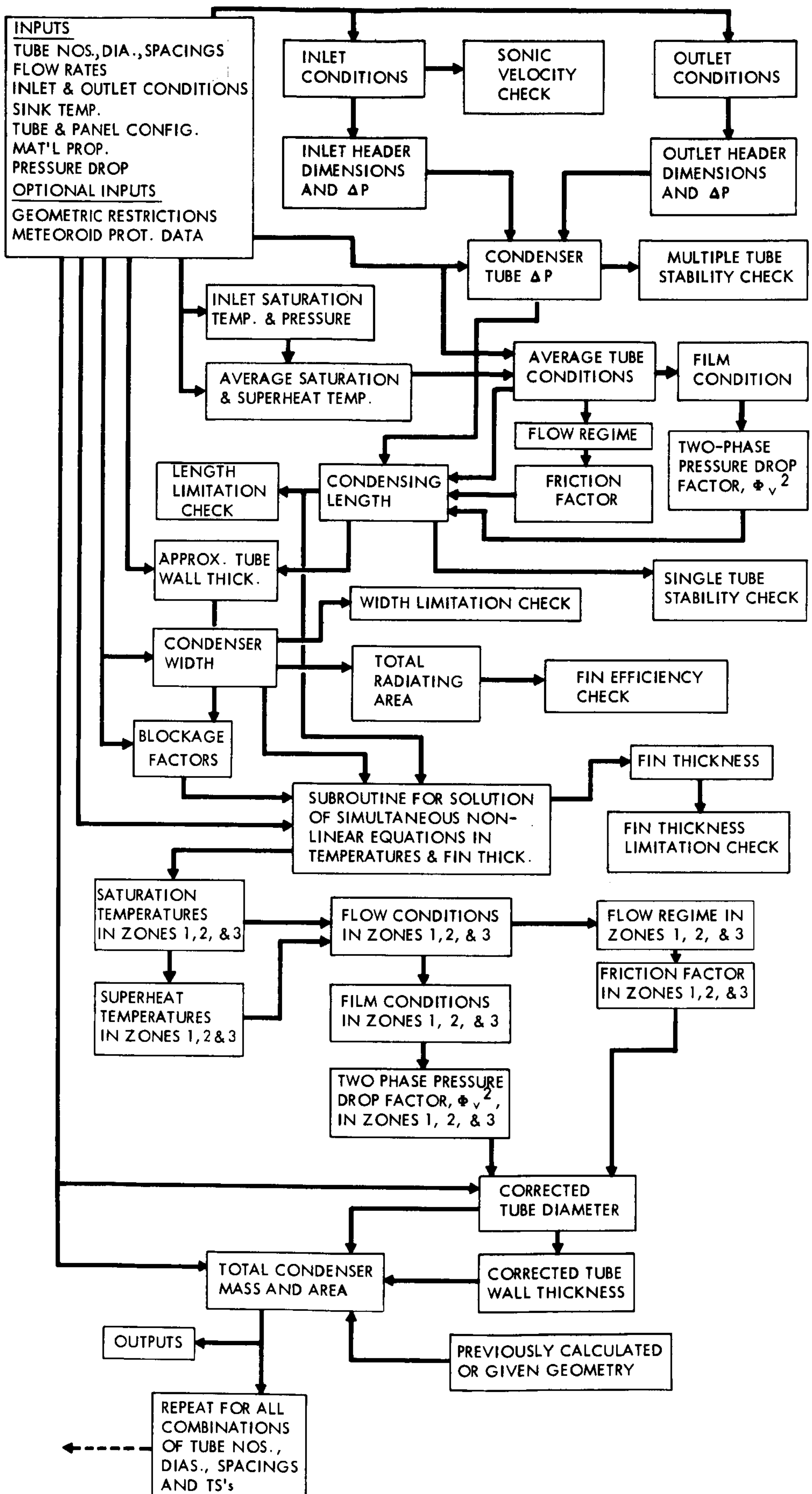


Figure 6

ISOTHERMAL DESIGN PROGRAM
INFORMATION FLOW CHART

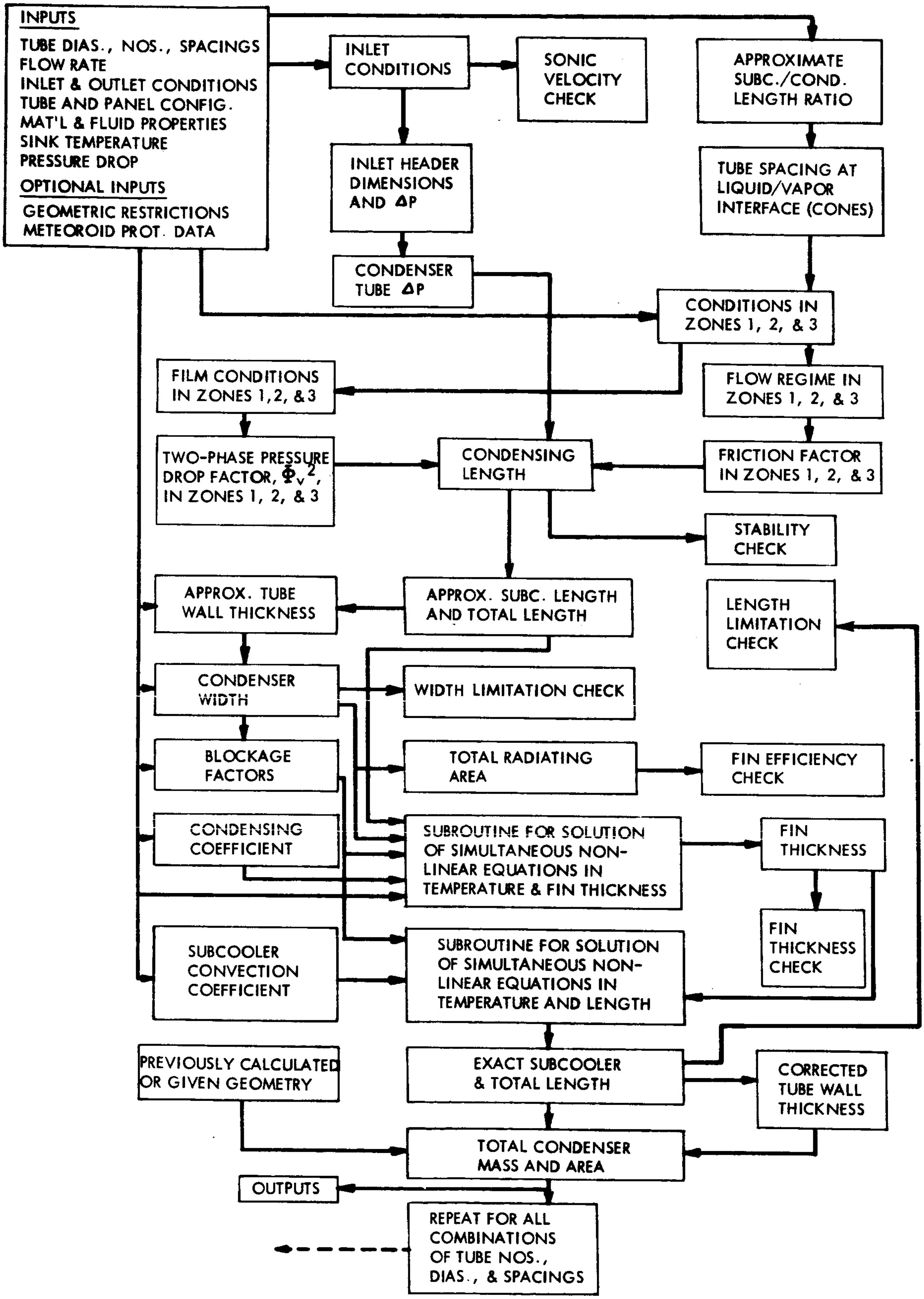


Figure 7

PRIMARY/SECONDARY DESIGN PROGRAM
INFORMATION FLOW CHART

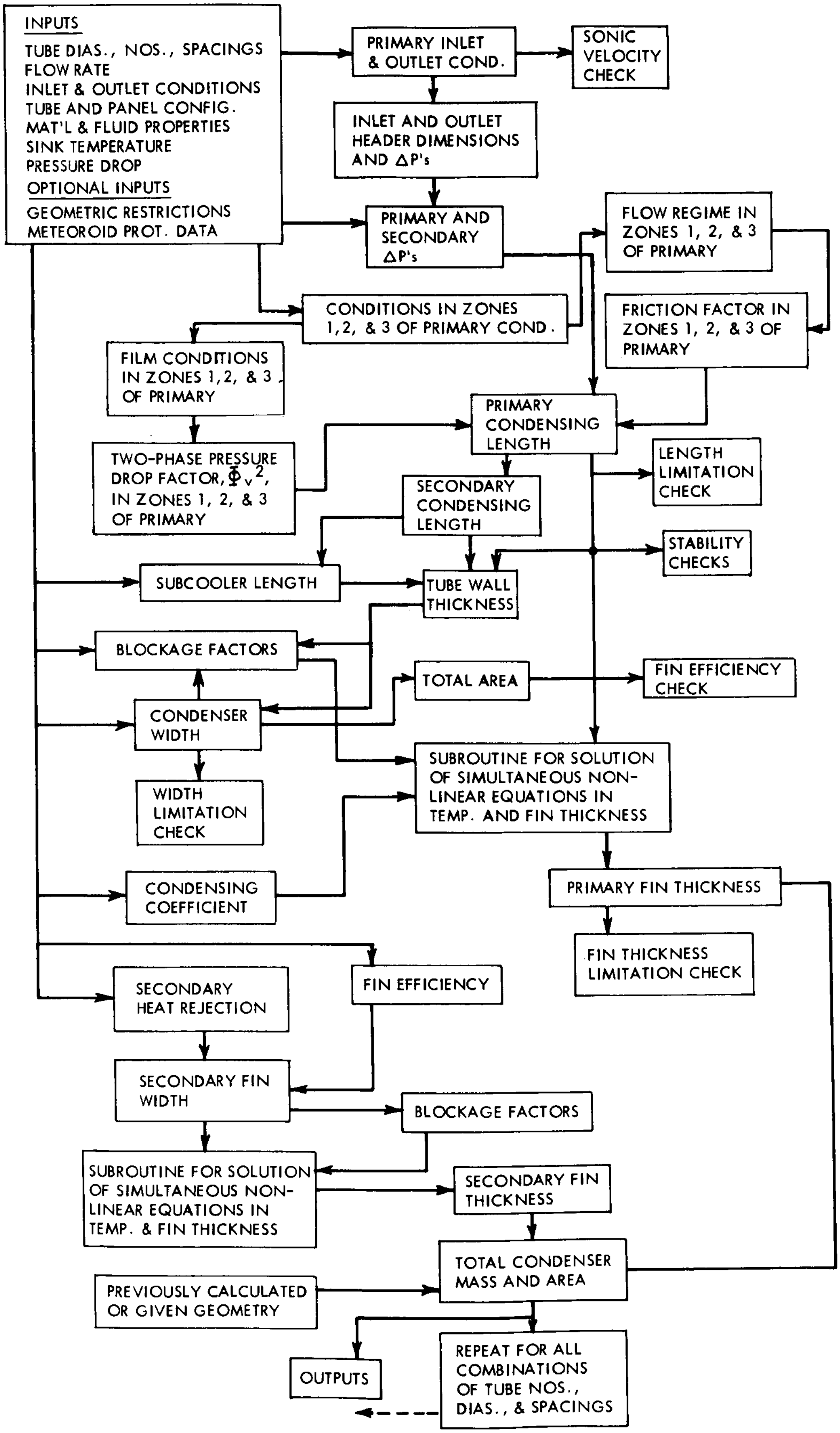


Figure 8

FUEL-CELL PERFORMANCE ANALYSIS PROGRAM
INFORMATION FLOW CHART

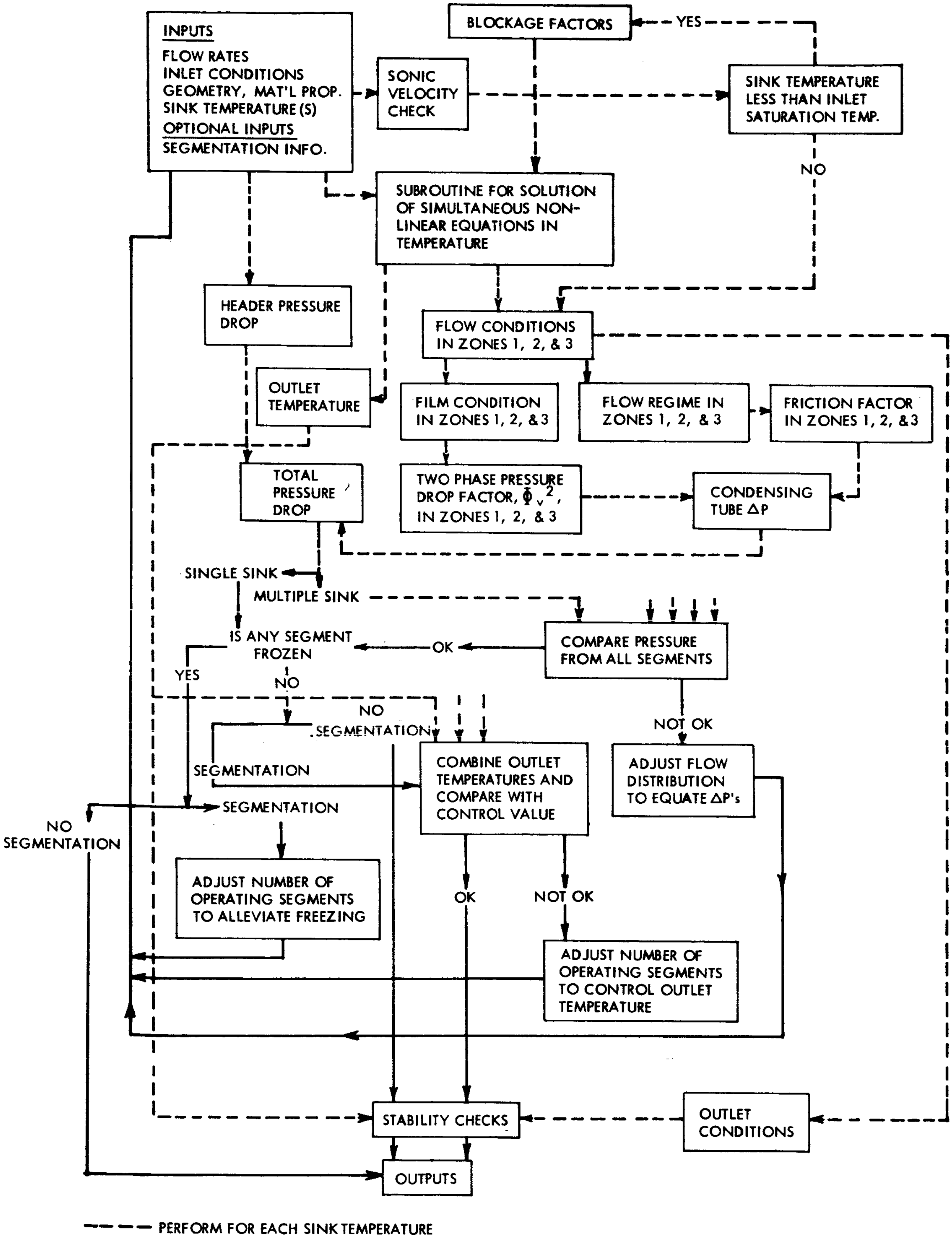


Figure 9

ISOTHERMAL PERFORMANCE ANALYSIS PROGRAM
INFORMATION FLOW CHART

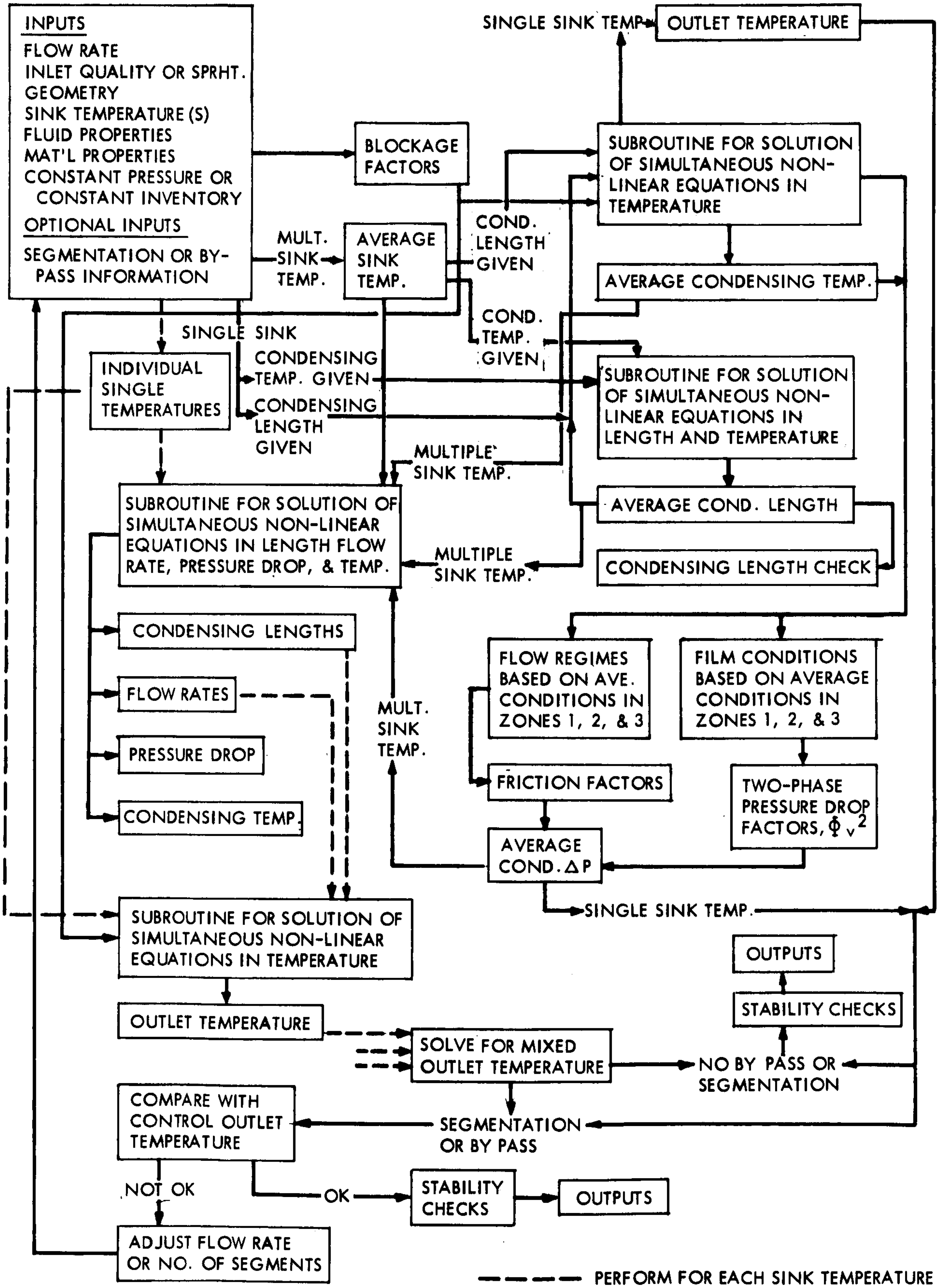


Figure 10

VALUES FOR CODEWORK "PUNT"

LETTER	NUMBER	MEANING
P	1 2 3	central fin open sandwich closed sandwich
U	1 2 3 4 5	flat plate cylinder triform cruciform cone
N	1 2	non-mercury working fluid mercury working fluid
T	1 2	liquid metal working fluid liquid non-metal working fluid

Figure 11

REMEDIES IN THE EVENT OF FAILURE TO PASS DIAGNOSTIC TESTS (DESIGN PROGRAMS, ONLY)

TEST NO.	TEST FAILED	ADJUSTMENT TO VALUES OF INDEPENDENT VARIABLES					
		DIAMETER		TUBE NUMBER		FIN HALF WIDTH	
		INCREASE	DECREASE	INCREASE	DECREASE	INCREASE	DECREASE
1	Sonic Velocity	X		X			
2	Frictional Press. Drop						X
3	Lower Length Limit Upper Length Limit	X 	 X	X 	 X		
4	Lower Width Limit Upper Width Limit					X 	 X
5	Lower Fin Thickness Limit Upper Fin Thickness Limit	 X	X 	 X	X 	 X	X
6	Lower Fin Efficiency Limit Upper Fin Efficiency Limit	 X	X 	 X	X 	 X	X
7	Gravitational Capability		X		X		
8	Secondary Fin Width (primary/secondary only)		X		X		
9	Saturation Temperature (fuel cell only)	(Not affected by variables - must lower outlet temperature or supply new set of inputs.)					
10	Non-Convergence	(Improbable design - no remedy.)					

Figure 12

PRINTOUTS IN THE EVENT OF FAILURE TO DESIGN
FUEL CELL DIRECT RADIATOR

(See Figure 12 if remedies are desired)

TEST NO.	PRINTOUT STATEMENT	MEANING
1	VMIN . . . GT (FSV)(SOVV)	sonic velocity exceeded
2	DPLC . . . NEGATIVE	insufficient frictional pressure drop
3	LC . . . OUT OF RANGE	length out of specified range
4	W . . . OUT OF RANGE	width out of specified range
5	TF . . . *OUT OF RANGE	fin thickness out of specified range
6	FEFF . . . OUT OF RANGE	fin efficiency out of range
7	N/A	
8	N/A	
9	STOP-TINSA NOT GREATER THAN TOUT	specified outlet temperature too high
10	20 CYCLES, 21 EQUATIONS NOT YET CONVERGED	matrix not converged

* If TF is negative, the actual fin efficiency is slightly greater than 1.0, and the rejection of this design was missed by Test 6.

Figure 13

PRINTOUTS IN THE EVENT OF FAILURE TO DESIGN
ISOTHERMAL DIRECT RADIATOR
(See Figure 12 if remedies are desired)

TEST NO.	PRINTOUT STATEMENT	MEANING
1	VIN . . . GREATER THAN (FSV) (SOVV)	sonic velocity exceeded
2	DPLC . . . NEGATIVE	insufficient friction pressure drop
3	LTX . . OUT OF RANGE	total length out of specified range
4	W . . . OUT OF RANGE	width out of specified range
5	TF . . . *OUT OF RANGE	fin thickness out of specified range
6	FEFF . . . OUT OF RANGE	fin efficiency out of range
7	N/A	
8	N/A	
9	N/A	
10	CONDENSER EQUATIONS NON-CONVERGENT AFTER 20 TRIES	condenser matrix not converged
	SUBCOOLER EQUATIONS NON-CONVERGENT AFTER 20 TRIES	subcooler matrix not converged

* If TF is negative, the actual fin efficiency is slightly greater than 1.0 and the rejection of this design was missed by Test 6.

Figure 14

PRINTOUTS IN THE EVENT OF FAILURE TO DESIGN
PRIMARY/SECONDARY DIRECT RADIATOR

(See Figure 12 if remedies are desired)

TEST NO.	PRINTOUT STATEMENT	MEANING
1	VIN . . . GT (FSV)(SOVV)	sonic velocity exceeded
2	DPLC . . . NEGATIVE	insufficient frictional pressure drop
3	LT . . . OUT OF RANGE	total length out of specified range
	LCP . . . OUT OF RANGE	primary condenser length out of specified range
4	W . . . OUT OF RANGE	width out of specified range
5	TFP . . . *OUT OF RANGE	primary fin thickness out of specified range
6	FEFF . . . OUT OF RANGE	primary fin efficiency out of range
7	NUE . . . OUT OF RANGE	gravitational capability out of specified range
8	WINS . . . OUT OF RANGE	secondary fin width negative
9	N/A	
10	PRIMARY CONDENSER EQUATIONS NON-CONVERGENT AFTER 20 TRIES	primary condenser matrix not converged
	SECONDARY CONDENSER EQUATIONS NON-CONVERGENT AFTER 20 TRIES	secondary condenser matrix not converged

* If TFP is negative, the actual fin efficiency is greater than 1.0, and the rejection of this design was missed by Test 6.

Figure 15

NOMENCLATURE

(For Analytical Section and Appendices A & B)

Symbols

A - area

C - volumetric heat capacity

c - specific heat

C_R - propogation velocity

D - tube diameter, inside; diffusion

d - differential

e - entrained

F - geometric view factor, force

f - Moody function factor

G - flow rate per unit cross-sectional area

g_s, g_c - gravitational conversion constant

h - heat transfer coefficient, enthalpy

J - Joule's constant

K - eddy diffusion coefficient, constant

k - thermal conductivity

L, l - length

L_e - Lewis number, $\rho c_p D / k$

M - molecular weight

m - flow rate

N - number of moles

Nu - Nusselt number,

n - number of g's

P - pressure

NOMENCLATURE (continued)
(For Analytical Section and Appendices A & B)

Symbols (continued)

Pr - Prandtl number, $c_p \mu / k$

Pe - Peclet number, Re Pr, $\rho D U c_p / k$

Q - heat transferred per unit area and time

q - heat transferred per unit time

R - gas constant

$\mathcal{R}$ - Universal gas constant

R_f - Reynold's number of condensate film,

Re - Reynold's number,

r - tube radius outside

rm - reciprocal mixing

Sc - Schmidt number, $\mu / \rho D_{12}$

sm - simple mixing

T - temperature (absolute)

t - thickness

U - velocity

V - volume

W - mass

W_v - Weber number of flowing vapor, $D \rho_v U_v^2 / 2 g_c \sigma$

W_f - Weber number of condensate film $U_2^2 \rho_f \delta / g_c \sigma$

ω - fin half width

X - quality

y - mole faction

NOMENCLATURE (continued)
(For Analytical Section and Appendices A & B)

Symbols (continued)

α - wave number, thermal diffusivity coefficient, absorptance

α_{ci} - wave growth factor

β - superheat factors, wave height

Λ - mass transfer coefficient

Δ - change

δ - film thickness, drop diameter

ϵ - thermal emittance (hemispherical), mass transfer constant, unbalance

Θ - time

μ - viscosity (absolute)

ρ - density

σ - Stefan-Boltzman constant, surface tension, mass transfer constant

τ - mission time, shear stress

ν - viscosity, kinematic

Φ_V^2 - two phase pressure drop modulus = $\Delta P_{TP} / \Delta P_V$

Φ_{12} - diffusion rate (component 1 into component 2, example)

Ω - collision integral

Subscripts

a - albedo

b - bulk

c - condensation, condensate

D - diffusion, design

e - exit

NOMENCLATURE (continued)
(For Analytical Section and Appendices A & B)

Subscripts (continued)

f - condensate, friction, fin

fv, fg - liquid-to-vapor phase change

G - geometry (diameter)

H - header

i - interface

in - inlet

ir - reference

INT - integrated

ℓ - liquid

m - mixture

mom - momentum

n - neutral

o - initial, inlet

out - outlet

P - pressure

q - heat transfer

S - solar, sink, static, sensible, superheat

SP - space

sat - saturation

T - total

TF - two-phase

t - thermal

v - vapor

w - wall

NOMENCLATURE (continued)
(For Analytical Section and Appendices A & B)

Subscripts (continued)

xx - two digit number referring to nodal point location

1 - condensable vapor

2 - noncondensable gas, vapor film interface

Superscripts

' - superheat, adjacent

* - transition

NOMENCLATURE

(For Users' Section and Appendices C & D)

SYMBOLS	DESCRIPTION	UNITS
ACR	area of entire condenser (one side) including subcooler, if applicable	ft^2
ACRP	total area of primary condenser (one side)	ft^2
ACRS	total area of secondary condenser (one side)	ft^2
ALPHS	solar absorptivity	
ALPHT	thermal absorptivity	
CL	specific heat of condensate	BTU/lb-^{o}F
CV	specific heat of vapor	BTU/lb-^{o}F
DCMAJ	diameter of conical panel at outlet	ft
DCMIN	diameter of conical panel at inlet	ft
DDEL	increment of tube diameter to be considered	in
DEHA	average inside diameter of outlet header	in
DIEHE	inside diameter of exit header at outlet	in
DIEP	inside diameter of condenser tube at outlet of primary condenser	in
DIHA	average inside diameter of inlet header	in
DIIN	inside tube diameter	in
DIIND	increment of DIIN to be considered	in
DIINF	largest value of DIIN to be considered	in
DIINH	inside diameter of inlet header at inlet	in
DIINO	smallest value of DIIN to be considered	in
DIINP	inside diameter of condenser tube at the inlet of the primary condenser	in
DIINP D	increment of DIINP to be considered	in
DIINP F	maximum value of DIINP to be considered	in

NOMENCLATURE (continued)
(For Users' Section and Appendices C & D)

SYMBOLS	DESCRIPTION	UNITS
DIINP 0	minimum value of DIINP to be considered	in
DIINS	inside diameter of condensing tube at the inlet to secondary condenser	in
DIINX	exact inside diameter of tube	in
DISC	inside diameter of subcooler tube	in
DMAX	maximum inside tube diameter to be considered	in
DMIN	minimum inside tube diameter to be considered	in
DOIN	outside tube diameter	in
DOINX	outside diameter of tube	in
DPEH	pressure drop in outlet header	psi
DPIH	pressure drop in inlet header	psi
DPLC	frictional pressure drop in condensing section	psi
DPLCP	frictional pressure drop, primary condenser	psi
DPLCS	frictional pressure drop, secondary condenser	psi
DPTM	mean static pressure loss across entire condenser	psi
DPTOT	overall static pressure loss	psi
EF	emissivity of fin coating	
ET	emissivity of tube coating	
FEFC	fin efficiency in condensing section	
FEFF	approximate fin efficiency	
FEFP	fin efficiency, primary condenser	
FEF1	fin efficiency of first third of condenser	
FEF2	fin efficiency of middle third of condenser	
FEF3	fin efficiency of last third of condenser	

NOMENCLATURE (continued)
(For Users' Section and Appendices C & D)

SYMBOL	DESCRIPTION	UNITS
FSV	maximum allowable Mach number of vapor, only	
GAMMA	ratio of specific heats of vapor	
GT	greater than	
HFG	heat of vaporization of working fluid	BTU/lb
KC	thermal conductivity of condensate	BTU/hr-ft-^{o}F
KF	thermal conductivity of fin material	BTU/hr-ft-^{o}F
KTH	thermal conductivity of tube material	BTU/hr-ft-^{o}F
LC	condensing length	ft
LCC	average condensing length	ft
LCG	specified average condensing length	ft
LCMAX	maximum allowable condensing length	ft
LCMIN	minimum allowable condensing length	ft
LCP	condensing length, primary condenser	ft
LCS	condensing length, secondary condenser	ft
-LNPO	the negative of the natural log of the probability of no meteoroid puncture in TAU days	
LPMAX	maximum length of primary condenser	ft
LPMIN	minimum length of primary condenser	ft
LSC	subcooler length	ft
LSCX	subcooler length	ft
LT	total condenser length (including subcooler)	ft
LTMAX	maximum total condenser length	ft
LTMIN	minimum total length	ft
LTX	total condenser length (including subcooler)	ft
M	working fluid molecular weight	lb_m/lb_{mole}

NOMENCLATURE (continued)
(For Users' Section and Appendices C & D)

SYMBOL	DESCRIPTION	UNITS
MACH	Mach number of vapor, only	
MCR	weight of entire condenser, including subcooler	lb
MDG	flow rate of noncondensable gas, H_2	lb/min
MDS	flow rate in individual segment	lb/min
MDT	total flow rate	lb/min
MDTG	total flow rate, $H_2 + H_2O$	lb/min
MDVE	total flow rate of water vapor at condenser outlet	lb/min
MDVIN	flow rate of water vapor at condenser inlet	lb/min
MEF	modulus of elasticity of fin material	psi
METH	modulus of elasticity of tube material	psi
MF	weight of fin	lb
MGI	flow rate of noncondensable gas per tube	lb/min
MHS	weight of all headers	lb
MIF	weight of inner fin (closed sandwich cone or cylinder)	lb
MIH	weight of inlet header	lb
MT	weight of tubes	lb
MVE	outlet water vapor flow rate per tube	lb/min
MVI	inlet water vapor flow rate per tube	lb/min
N	total number of tubes	
N D	increment of N to be considered	
N F	maximum value of N to be considered	
N O	minimum value of N to be considered	
ND	increment of N to be considered	
NDEL	increment of N to be considered	

NOMENCLATURE (continued)
(For Users' Section and Appendices C & D)

SYMBOL	DESCRIPTION	UNITS
NF	largest value of N to be considered	
NMAX	maximum value of N to be considered	
NMIN	minimum value of N to be considered	
NO	smallest value of N to be considered	
NOS	number of different sink temperature values	
NPG	gravitational capability based on multiple tube stability	g's
NS·S	total number of segments operating	
NUE	gravitational capability based on film transport	g's
NUEG	minimum gravitational capability	g's
PBP	proportional bypass code (see paragraph 7.4.2)	
PC	average condensing pressure	psia
PIR	reference saturation pressure (see paragraph 7.4.4)	psia
PM	total pressure	psia
POMIX	outlet water vapor partial pressure at TOMIX	psia
PPWR	equivalent pump power consumed in radiator (assumes 100% efficient pump - not applicable to compressor systems)	HP
PUNT	tube-fin, panel and working fluid description (see figure 11)	
QFT	total fin heat rejection	BTU/hr
QFTC	fin heat rejection in condensing section	BTU/hr
QFTOT	total fin heat rejection	BTU/hr
QSC	subcooler heat rejection	BTU/hr
QTOT	total heat rejection	BTU/hr
QTOTC	total heat rejection in condensing section	BTU/hr

NOMENCLATURE (continued)
(For Users' Section and Appendices C & D)

SYMBOL	DESCRIPTION	UNITS
QTOTP	heat rejection, primary condenser	BTU/hr
QTOTS	total heat rejection in subcooler (not applicable to primary/secondary)	BTU/hr
QTOTS	latent heat rejection, secondary condenser	BTU/hr
QTT	total tube heat rejection	BTU/hr
QTTC	tube heat rejection in condensing section	BTU/hr
QTTOT	total tube heat rejection	BTU/hr
R	gas constant	$lb_f ft/^oR\ lb_m$
RHIF	density of internal fin material, closed sandwich cone or cylinder	lb/ft^3
RHOF	density of fin material	lb/ft^3
RHOH	density of header material	lb/ft^3
RHOIF	density of internal fin material, closed sandwich cone or cylinder	lb/ft^3
RHOL	density of condensate	lb/ft^3
RHOT	density of tube material	lb/ft^3
S	total number of segments available (in entire condenser)	
S·NS	number of segments operating	
SHIN	inlet specific humidity	
SHOUT	specific humidity resulting from mixture of outlet flows of all segments	
SOVV	sonic velocity of the vapor, only	ft/sec
SUFT	liquid-vapor surface tension	lb/ft
T	temperature	^oR
TAU	mission time	days
TC	average condensing temperature	^oR
TCG	given condensing temperature	^oR

NOMENCLATURE (continued)
(For Users' Section and Appendices C & D)

SYMBOL	DESCRIPTION	UNITS
TCAPG	approximate condensing temperature	^{o}R
TCM	mean condensing temperature	^{o}R
TF	fin thickness	in
TFIN	fin thickness at condenser inlet	in
TFMAX	maximum allowable TF fin thickness	in
TFMIN	minimum allowable fin thickness (both fins in a closed sandwich non-cone)	in
TFOUT	fin thickness at condenser outlet	in
TFP	fin thickness, primary condenser	in
TFS	fin thickness, secondary condenser	in
TH	given header wall thickness	in
THETA	fraction of inlet flow, by-passed	
TIF	internal fin thickness, closed sandwich cone or cylinder	in
TIMTC	inlet superheat	^{o}R
TIN	inlet temperature	^{o}R
TINSA	inlet water vapor saturation temperature	^{o}R
TIR	reference saturation temperature (at PIR) (see paragraph 7.4.4)	^{o}R
TMIXG	target outlet mixture temperature	^{o}R
TMIXX	temperature resulting from mixing of by-passed vapor and condensate from condenser	^{o}R
TOMIX	temperature resulting from mixture of the outlet flows of all segments	^{o}R
TOU	individual segement outlet saturation temperature	^{o}R
TOUT	outlet fluid temperature of individual segment	^{o}R
TOUTM	mixed outlet target temperature	^{o}R

NOMENCLATURE (continued)
(For Users' Section and Appendices C & D)

SYMBOL	DESCRIPTION	UNITS
TS	sink temperature	^{o}R
TTG	given tube wall thickness (will cause by-pass of meteoroid protection requirement)	in
TTP	tube wall thickness, primary condenser	in
TTX	tube wall thickness	in
T10	saturation temperature 1/6 of the way through the condenser	^{o}R
T20	saturation temperature 1/2 of the way through the condenser	^{o}R
T30	saturation temperature 5/6 of the way through the condenser	^{o}R
VIN	vapor velocity at inlet	ft/sec
VISL	absolute viscosity of condensate	lb/ft-sec
VISV	absolute viscosity of vapor	lb/ft-sec
VME	velocity of mixture at condenser outlet	ft/sec
VMIN	inlet mixture velocity	ft/sec
W	total condenser width	ft
WBARE	total condenser width at outlet (in triform, three times single panel width, etc.)	ft
WBARI	total condenser width at inlet	ft
WBREX	condenser total width at outlet	ft
WBRIX	total condenser width at inlet	ft
WIN D	increment of fin half-width to be considered	in
WIN DEL	increment of fin half-width to be considered	in
WIN F	maximum value of fin half-width to be considered	in
WIN MAX	maximum value of fin half-width to be considered	in

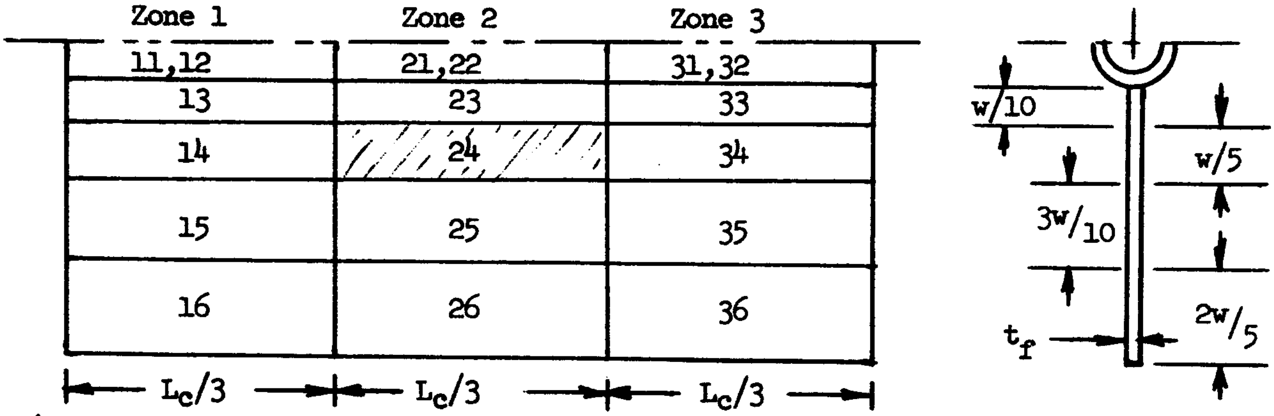
NOMENCLATURE (continued)
(For Users' Section and Appendices C & D)

SYMBOL	DESCRIPTION	UNITS
WIN MIN	minimum value of fin half-width to be considered	in
WIN O	minimum value of fin half-width to be considered	in
WINA	fin half-width	in
WINA D	increment of fin half-width to be considered	in
WINA F	largest value of fin half-width to be considered	in
WINA O	smallest value of fin half-width to be considered	in
WINS	fin half-width, secondary condenser	in
WINX	fin half-width at inlet	in
WINXX	fin half-width at inlet	in
WMAX	maximum allowable total condenser width (in triform three times single panel width, etc.)	ft
WMIN	minimum allowable total condenser width	ft
WOUX	fin half-width at outlet	in
WOUXX	fin half-width at outlet	in
XIN	inlet quality	

APPENDIX A-1

TYPICAL NODAL POINT HEAT FLOW SUMMATION

Consider fin nodal point 24 (second zone, fourth nodal point) of a typical condensing section (see sketch below and Figure 4 of text).



(The nomenclature used in Appendix A is identical to that used in the Analytical Section, see Nomenclature Section.)

For steady state conditions, the summation of heat flows around nodal point 24 is equal to zero:

$$\frac{L_c}{3}\ t_f\ K_f\ \frac{(T_{23} - T_{24})}{\frac{3\,w}{20}}$$ conduction from 23 to 24

$$+\ \frac{w}{5}\ t_f\ K_f\ \frac{(T_{14} - T_{24})}{\frac{L_c}{3}}$$ conduction from 14 to 24

$$-\ \frac{L_c}{3}\ t_f\ K_f\ \frac{(T_{24} - T_{25})}{\frac{5\,w}{20}}$$ conduction from 24 to 25

$$-\ \frac{w}{5}\ t_f\ K_f\ \frac{(T_{24} - T_{34})}{\frac{L_c}{3}}$$ conduction from 24 to 34

$$- \; 2 \; \frac{w}{5} \; \frac{L_c}{3} \; \sigma \; \epsilon_f \; F_{24 \rightarrow SP} \; (T_{24}^{\;4} - T_{sink}^{\;4})$$ net radiation exchange between 24 (both sides) and space

$$= \; 0$$

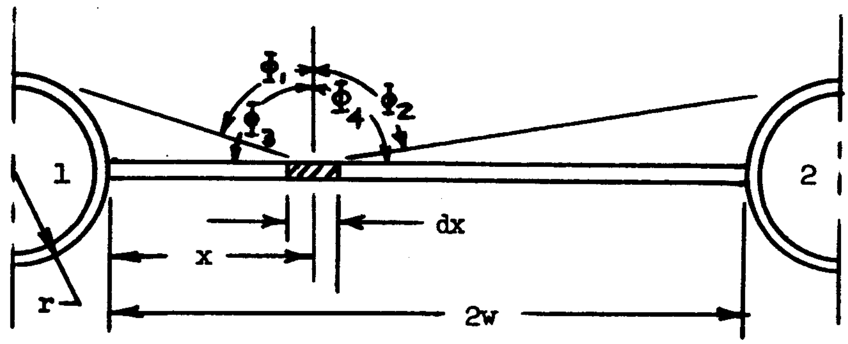
Note: Conduction through fin, perpendicular to fin faces, is assumed infinite.

These summations are written for all the applicable nodal points and solved simultaneously to obtain the temperatures.

APPENDIX A-2

RADIATION BLOCKAGE FACTORS

Consider a central fin configuration as shown below (also see Figure 4 of text).



From reference 16, the view factor from an element dx to tube 1, F_{dx-1}, is:

$$F_{dx \rightarrow 1} = \frac{\sin \Phi_3 - \sin \Phi_1}{2} \qquad \text{(A-1)}$$

assuming an infinitely long tube. This latter assumption introduces negligible error since reference 27 shows that the change in view factor with tube length is negligible once the tube length exceeds the width of dx.

Evaluating $F_{dx \rightarrow 1}$:

$$\sin \Phi_1 = \frac{\sqrt{(r + x)^2 - r^2}}{r + x}$$

$$\sin \Phi_3 = 1.0$$

$$F_{dx \rightarrow 1} = \frac{1}{2} \left[1 - \frac{\sqrt{(r + x)^2 - r^2}}{r + x} \right] \qquad \text{(A-2)}$$

Similarly:

$$F_{dx \rightarrow 2} = \frac{1}{2} \left[1 - \frac{\sqrt{(2 w + r - x)^2 - r^2}}{2 w + r - x} \right] \qquad \text{(A-3)}$$

In both cases, the fin thickness is assumed negligible from a geometrical standpoint. The view factor of the total fin width 2 w to tube 1 can be found by integrating:

$$F_{2w \rightarrow 1} = \frac{1}{2w} \int_{o}^{2w} (F_{dx \rightarrow 1})\, dx \qquad \text{(A-4)}$$

$$= \frac{1}{2} - \frac{1}{2}\sqrt{\frac{r}{w} + 1} + \frac{r}{4w} \cos^{-1}\left(\frac{1}{1 + \frac{2w}{r}}\right)$$

Using:

$$A_j F_{j \rightarrow k} = A_k F_{k \rightarrow j} \quad \text{and} \quad \sum_{k=1}^{k=n} F_{j-k} = 1$$

the following can be derived:

$$F_{1 \rightarrow 2w} = \frac{4}{\pi} \frac{w}{r} F_{2w \rightarrow 1}$$

$$F_{2w \rightarrow SP} = 1 - 2 F_{2w \rightarrow 1}$$

$$F_{SP \rightarrow 2w} = \left(\frac{1}{1 + \frac{r}{w}}\right) F_{2w \rightarrow 1}$$

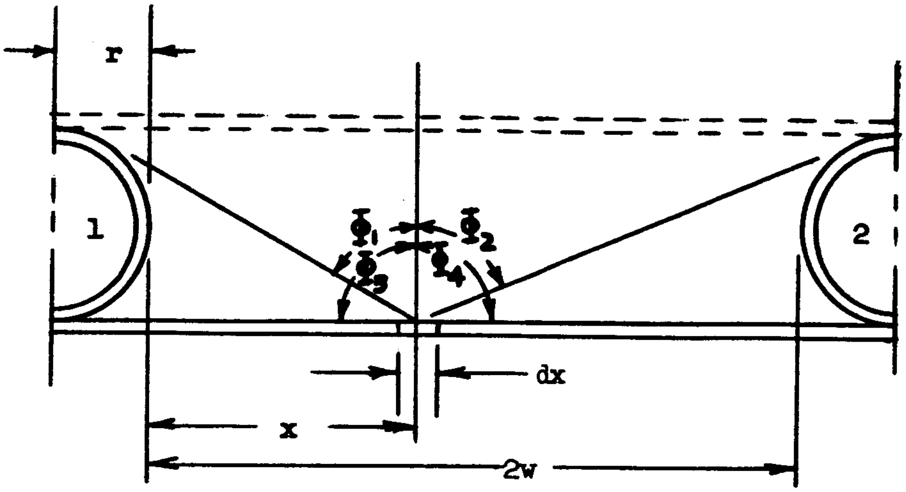
$$F_{SP \rightarrow 1} = \frac{1}{2}\left[1 - F_{SP \rightarrow 2w}\right]$$

$$F_{1 \rightarrow SP} = \frac{4}{\pi}\left(1 + \frac{w}{r}\right) F_{SP \rightarrow 1}$$

$$= \frac{2}{\pi}\left[1 + \frac{w}{r}\left(1 - \sqrt{\frac{r}{w} + 1}\right) + \frac{1}{2} \cos^{-1}\left(\frac{1}{1 + \frac{2w}{r}}\right)\right] \qquad \text{(A-5)}$$

Equation A-5 represents the geometric view factor of a tube (for a central fin-tube configuration) to space.

For an open or closed sandwich tube-fin configuration:



the incremental fin area to tube view factor can again be expressed as:

$$F_{dx \rightarrow 1} = \frac{\sin \Phi_3 - \sin \Phi_1}{2} \qquad \text{(A-6)}$$

where

$$\sin \Phi_3 = 1$$

and

$$\Phi_1 = 90 - 2 \cos^{-1} \left[\frac{r + x}{\sqrt{(r + x)^2 + r^2}} \right]$$

$$\cos \frac{1}{2} (90 - \Phi_1) = \frac{r + x}{\sqrt{(r + x)^2 + r^2}}$$

$$\sqrt{\frac{1 + \cos (90 - \Phi_1)}{2}} = \frac{r + x}{\sqrt{(r + x)^2 + r^2}}$$

$$1 + \sin \Phi_1 = \frac{2 (r + x)^2}{(r + x)^2 + r^2}$$

$$\sin \Phi_1 = \frac{(r + x)^2 - r^2}{(r + x)^2 + r^2}$$

and substituting into (A-6) yields:

$$F_{dx \rightarrow 1} = \frac{1}{2}\left[1 - \frac{(r + x)^2 - r^2}{(r + x)^2 + r^2}\right] \qquad \text{(A-7)}$$

Similarly:

$$F_{dx \rightarrow 2} = \frac{1}{2}\left[1 - \frac{(2\,w + r - x)^2 - r^2}{(2\,w + r - x)^2 + r^2}\right] \qquad \text{(A-8)}$$

Again, the view factor of the total fin width 2 w to tube 1 can be found by integrating:

$$F_{2\,w \rightarrow 1} = \frac{1}{2w}\int_0^{2w} (F_{dx \rightarrow 1})\, dx \qquad \text{(A-9)}$$

$$= \frac{r}{2w}\left[\tan^{-1}\left(1 + \frac{2w}{r}\right) - \frac{\pi}{4}\right]$$

Again, by view factor algebra:

$$F_{1 \rightarrow SP} = \frac{2}{\pi}\left(1 + \frac{w}{r}\right) F_{SP \rightarrow 1}$$

$$= \frac{1}{\pi}\left[1 + \tan^{-1}\left(1 + \frac{2w}{r}\right) - \frac{\pi}{4}\right] \qquad \text{(A-10)}$$

Equation (A-10) represents the geometric view factor for tubes to space for open sandwich construction (not applicable for closed sandwich).

The exact expression for the view factor of a fin element between limits of x_1 and x_2 to both tubes 1 and 2 can be found by integrating the following equation:

$$F_{x_1 x_2 \rightarrow 1,2} = \frac{1}{A_{x_1 x_2}} \int_{x_1}^{x_2} \left[(F_{dx \rightarrow 1}) + (F_{dx \rightarrow 2})\right] dx \qquad \text{(A-11)}$$

For example, the resulting expression for a typical nodal point between $x_1 = \frac{w}{10}$ and $x_2 = \frac{3w}{10}$ (nodal point 4) for a central fin configuration yields:

$$F_{\frac{w}{10}, \frac{3w}{10} \rightarrow 1,2} = \frac{1}{2}\left[2 - \frac{1}{2}\sqrt{9 + \frac{60r}{w}} + \frac{5r}{w}\cos^{-1}\left(\frac{1}{\frac{3w}{10r} + 1}\right)\right.$$

$$+ \frac{1}{2}\sqrt{1 + \frac{20r}{w}} - \frac{5r}{w}\cos^{-1}\left(\frac{1}{\frac{w}{10r} + 1}\right) + \frac{1}{2}\sqrt{289 + \frac{340r}{w}}$$

$$- \frac{5r}{w}\cos^{-1}\left(\frac{1}{\frac{17w}{10r} + 1}\right) - \frac{1}{2}\sqrt{361 + \frac{380r}{w}}$$

$$\left. + \frac{5r}{w}\cos^{-1}\left(\frac{1}{\frac{19w}{10r} + 1}\right)\right] \qquad \text{(A-12)}$$

Obviously, equations for fin segments-to-tube view factors similar to equation (A-12) are lengthy and would add vast complexity to the simultaneous nodal point equation solution.

If it is assumed that the view factor from a fin segment to both tubes is constant between the limits of x_1 and x_2 and equal to the point to tubes view factor at the $(x_1+x_2)/2$ location, the following simpler expression could be used:

$$F_{x_1x_2 \rightarrow 1,2} = F_{dx \rightarrow 1} + F_{dx \rightarrow 2} \qquad \text{(A-13)}$$

For the location investigated in equation (A-12), the view factor would equal

$$F_{\frac{w}{10}, \frac{3w}{10} \rightarrow 1,2} = 1 - \frac{\sqrt{.4\frac{r}{w} + .04}}{2\frac{r}{w} + .4} - \frac{\sqrt{3.24 + 3.6\frac{r}{w}}}{2\frac{r}{w} + 3.6} \qquad \text{(A-14)}$$

A comparison between values for view factors using equation (A-11) and those obtained using equation (A-13) was made.

Figure A-1 (Figures for Appendix A can be found at the end of the appendix) shows the comparison of the integrated values of F for the four sections compared with the value at the center assuming r/w = 1 (considered an upper limit).

Evaluating now the view factor 3 to 1 (largest error) for r/w = 0.1 (considered a lower limit) results in:

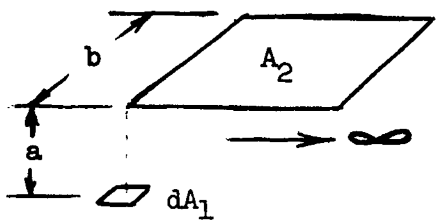
Integrated Value: .1576
Mid-Point Value: .1274
% Error = 19.16%

Without going through all the possible values of r/w, it appears as if the maximum error in fin-to-tube view factor will occur at low r/w in section 3 (closest to tube). Since this error will probably not exceed 20% and since it affects only about 20% of the total heat rejected from the condenser, the maximum error in overall condenser heat rejection should not exceed 4% if the mid-point view factors rather than integrated ones are used.

Figures A-2 and A-3 list these mid-point view factors for central fin and open and closed sandwich.

In the case of the closed sandwich, furthermore, there exist fin-to-fin view factors. It can be appreciated that, if all possible fin-to-fin view factors are considered, the resulting sixty-four coefficients would unnecessarily complicate the program. We will, therefore, examine the array and see if any may be neglected.

From reference 16 the following can be written:



$$B \equiv \frac{b}{a}$$

$$F_{dA_1 \rightarrow A_2} = \frac{B}{4\sqrt{1 + B^2}}$$

Applying this equation to the view factor from section 3 on one fin to section 4 of the opposite fin (remembering we have a closed sandwich) results in:

r/w	$F_{3 \rightarrow 4'}$
.5	.096
.2	.203
.1	.270

Now investigating the view factor from 3 to other opposite areas for r/w = .10 (worst case) results in:

Areas Considered	View Factor
$F_{3 \rightarrow 4'}$	.270
$F_{3 \rightarrow 5'}$	.078
$F_{3 \rightarrow 6'}$	.021

Based on these results, it is felt that fin-to-fin view factors for the closed sandwich beyond one section to either side of the section in question are negligible.

The required view factors then are:

$$F_{3 \rightarrow 4'} = \frac{w/r}{16\sqrt{1 + .01625\,(w/r)^2}} - \frac{w/r}{80\sqrt{1 + .000625\,(w/r)^2}}$$

$$F_{4 \rightarrow 5'} = \frac{w/r}{10\sqrt{1 + .04\,(w/r)^2}} - \frac{w/r}{40\sqrt{1 + .0025\,(w/r)^2}}$$

$$F_{5 \rightarrow 6'} = \frac{w/r}{7.2727\sqrt{1 + .07563(w/r)^2}} \quad \frac{w/r}{26.667\sqrt{1 + .005625(w/r)^2}}$$

$$F_{4 \rightarrow 3'} = \frac{1}{2}\, F_{3 \rightarrow 4'}$$

$$F_{5 \rightarrow 4'} = \frac{2}{3}\, F_{4 \rightarrow 5'}$$

$$F_{6 \rightarrow 5'} = \frac{3}{4}\, F_{5 \rightarrow 6'}$$

However, as explained in paragraph 3.1.2, the overall effect of these fin-to-fin view factors in the closed sandwich construction were considered negligible and no thermal interaction was considered between the fins. The view factors of Figures A-2 and A-3, however, are calculated and used in all the programs.

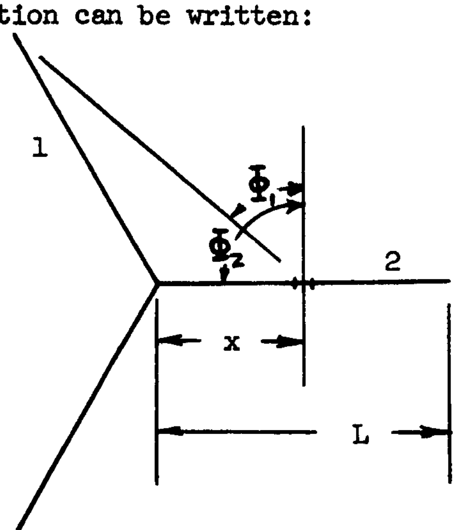
APPENDIX A-3

PANEL-TO-PANEL VIEW FACTOR

Triform

From reference 16 the following equation can be written:

Note: Infinite length perpendicular to paper



$$F_{dx \rightarrow 1} = \frac{1}{2}\left(\sin \Phi_2 - \sin \Phi_1\right) \qquad \text{(A-15)}$$

$$= \frac{1}{2}\left[1 - \frac{x + L\cos 60^\circ}{\sqrt{(x - L\cos 60^\circ)^2 + (L\sin 60^\circ)^2}}\right]$$

$$= \frac{1}{2}\left[1 - \frac{x + .5\,L}{\sqrt{(x + .5\,L)^2 + .75\,L^2}}\right]$$

let $y = x/L$

$$F_{dx \rightarrow 1} = \frac{1}{2}\left[1 - \frac{y + .5}{\sqrt{(y + .5)^2 + .75^2}}\right] \qquad \text{(A-16)}$$

$$F_{2 \rightarrow 1} = \frac{1}{L}\int_0^1 \frac{1}{2}\left[1 - \frac{y + .5}{\sqrt{(y + .5)^2 + .75^2}}\right] L\,dy$$

Let $u = y + .5$

$$F_{2\rightarrow 1} = \frac{1}{2} \int_{.5}^{1.5} \left[1 - \frac{u}{\sqrt{u^2 + .75^2}} \right] du$$

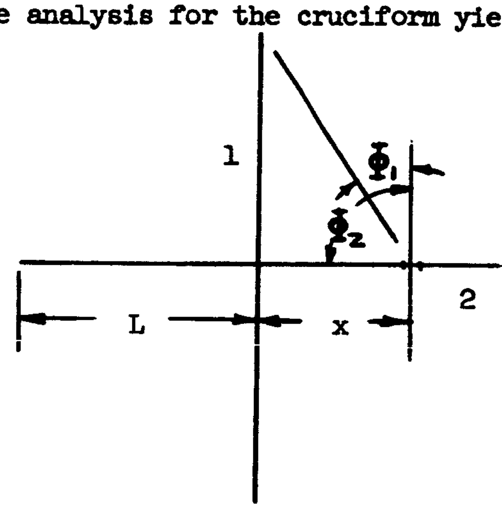
$$= \frac{1}{2} - \frac{1}{2} \left[\sqrt{u^2 + .75^2} \right]_{.5}^{1.5} = .134$$

$$\therefore F_{2\rightarrow \text{space}} = 1 - .134 = .866$$

Evaluating (A-16) on a local basis results in the upper curve of Figure A-4.

Cruciform

Performing the same analysis for the cruciform yields:



Again, for infinite dimension perpendicular to paper

$$F_{dx\rightarrow 1} = \frac{1}{2} \left[\sin \Phi_2 - \sin \Phi_1 \right]$$

$$= \frac{1}{2} \left[1 - \frac{x}{\sqrt{x^2 + L^2}} \right] \tag{A-17}$$

Let $y = \frac{x}{L}$

$$F_{dx\rightarrow 1} = \frac{1}{2} \left[1 - \frac{y}{\sqrt{y^2 + 1}} \right]$$

$$F_{2\rightarrow 1} = \frac{1}{L} \int_{o}^{1} \frac{1}{2} \left[1 - \frac{y}{\sqrt{y^2 + 1}} \right] L\, dy$$

$$= \frac{1}{2} - \frac{1}{2} \left[\sqrt{y^2 + 1} \right]_0^1$$

$$= \frac{1}{2} - \frac{\sqrt{2}}{2}$$

$$= .283$$

$$F_{2 \rightarrow space} = .707$$

Equation (A-17) is plotted as the lower curve in Figure A-4.

APPENDIX A-4

HEAT AND MASS TRANSFER COEFFICIENT FOR HYDROGEN AND WATER VAPOR MIXTURE

In determining the heat transfer from a two-component condensing mixture, it is convenient to determine the sensible heat transfer coefficient and then, realizing the potential for latent heat transfer is coupled to the potential for sensible heat transfer through the Clausius-Clapeyron equation, determine the ratio of latent to sensible heat transfer coefficients.

Finding first, then, the sensible coefficient:

$$\frac{h\,D}{k} = .0265 \left(\frac{DG}{\mu}\right)^{.8} \left(\frac{C\mu}{k}\right)^{.3}$$

$$h = .0265\ G^{.8}\ \frac{k^{.7}}{D^{.2}}\ \frac{C^{.3}}{\mu^{.5}}$$

also

$$G = \frac{m_1 + m_2}{\pi D^2/4} = \frac{m_2}{\pi D^2/4} \left(\frac{m_1}{m_2} + 1\right) = G_2 \left(\frac{m_1}{m_2} + 1\right)$$

$$G = G_2\ \frac{R_2}{R_1} \left(\frac{P_1}{P_m - P_1}\right) = G_2\ \frac{R_2}{R_1} \left[\frac{1}{(P_m/P_1) - 1}\right]$$

$$\therefore h = .0265\ \frac{G_2^{.8}}{D^{.2}} \left(\frac{R_2}{R_1}\right)^{.8} \left[\frac{1}{(P_m/P_1) - 1}\right]^{.8} \frac{k^{.7} C^{.3}}{\mu^{.5}} \qquad \text{(A-18)}$$

See expressions for C and μ as functions of T, Pm on following pages.

Viscosity of Mixture

Wilke's equation for binary mixtures at low pressure (reference 28)

$$\mu = \frac{\mu_1}{1 + (y_2/y_1)\,\Phi_{12}} + \frac{\mu_2}{1 + (y_1/y_2)\,\Phi_{21}} \qquad \text{(A-19)}$$

$$\Phi_{12} = \frac{\left[1 + (\mu_1/\mu_2)^{\frac{1}{2}}\ (M_2/M_1)^{\frac{1}{4}}\right]^2}{2\sqrt{2}\ (1 + M_1/M_2)^{\frac{1}{2}}}$$

$$\Phi_{21} = \frac{\left[1 + (\mu_2/\mu_1)^{\frac{1}{2}} \ (M_1/M_2)^{\frac{1}{4}}\right]^2}{2\sqrt{2} \ (1 + M_2/M_1)^{\frac{1}{2}}}$$

y_1 and y_2 are the mole fractions of the components, therefore,

$$\frac{y_2}{y_1} = \frac{P_2}{P_1} = \frac{P_m - P_1}{P_1} = \frac{P_m}{P_1} - 1 \qquad \text{Note: } y_1 = N_1/N_m = P_1/P_m$$

and

$$\frac{y_1}{y_2} = \frac{P_1}{P_m - P_1} = \frac{1}{(P_m/P_1) - 1}$$

From the Clapeyron relation,

$$P_1 = P_{ir} \exp\left\{\frac{h_{fvi} \ J}{R_1 T}\left[\frac{T}{T_{ir}} - 1\right]\right\} \qquad \text{Note: } \exp A \equiv e^A$$

and

$$\frac{P_m}{P_1} = \frac{P_m}{P_{ir}} \exp\left(\frac{h_{fvi} \ J}{R_1 \ T}\right)\left(1 - \frac{T}{T_{ir}}\right)$$

which makes y_2/y_1 and y_1/y_2 functions of T and P_m, as a result, μ = function (T, P_m) for given components 1 and 2.

Specific Heat of Mixture

$$c = \frac{m_1 \ c_1}{m_1 + m_2} + \frac{m_2 \ c_2}{m_1 + m_2}$$

$$c = \frac{c_1 + (m_2/m_1) \, c_2}{1 + (m_2/m_1)}$$

For a gaseous mixture of perfect gas,

$$P_1/P_2 = \frac{m_1 \ M_2}{m_2 \ M_1}$$

$$\frac{m_2}{m_1} = \frac{P_2 \ M_2}{P_1 \ M_1} = \frac{(P_m - P_1)}{P_1} \ \frac{M_2}{M_1} = \left(\frac{P_m}{P_1} - 1\right) \frac{M_2}{M_1}$$

$$c = \frac{c_1 + \left[(P_m/P_1) - 1\right] M_2/M_1 \; C_2}{1 + \left[(P_m/P_1) - 1\right] M_2/M_1} \tag{A-20}$$

Mixture Thermal Conductivity

$$k_m = \frac{1}{2}\left(k_{sm} + k_{rm}\right) \qquad \text{(Reference 28)}$$

$$k_{sm} = x_1 k_1 + x_2 k_2 \quad \text{and} \quad \frac{1}{k_m} = \frac{x_1}{k_1} + \frac{x_2}{k_2}$$

x_1, x_2 = mole fractions

In terms of our nomenclature:

$$k_{sm} = \frac{N_1 k_1}{N_1+N_2} + \frac{N_2 k_2}{N_1+N_2} = \left(\frac{P_1}{P_m}\right)^{k_1} + \left(\frac{P_2}{P_m}\right)^{k_2} = \left(\frac{P_1}{P_m}\right)^{k_1} + \left(\frac{P_m - P_1}{P_m}\right)^{k_2}$$

$$\frac{1}{k_{rm}} = \left(\frac{P_1}{P_m}\right)\frac{1}{k_1} + \left(\frac{P_2}{P_m}\right)\frac{1}{k_2} = \frac{P_1}{P_m K_1} + \frac{P_m - P_1}{P_m k_2}$$

Note: P_1 is a function of T (Clapeyron's relation), therefore, k_m becomes a function of temperature.

$$2\,k_m = \frac{P_1 k_1}{P_m} + \left(\frac{P_m - P_1}{P_m}\right) k_2 + \frac{1}{P_1/P_m\, k_1 + (P_m - P_1)/P_m\, k_2}$$

$$2\,k_m = \frac{P_1}{P_m}\left(k_1 - k_2\right) + k_2 + \frac{1}{P_1/P_m\left(\frac{1}{k_1} - \frac{1}{k_2}\right) + \frac{1}{k_2}} \tag{A-21}$$

Combining equations A-18, A-19, A-20 and A-21 for a hydrogen-water vapor mixture (saturated) results in:

$$h = \frac{G^{.8}}{D^{.2}}\left(\frac{1}{60}\right) f\,(T)$$

where:
- h is in Btu/hr-ft^2-^{o}F
- G is in lb/ft^2-hr
- D is in ft
- f(T) is in $\dfrac{\text{Btu sec}^{.5}}{\text{hr}^{.7}\ \text{ft}^{.2}\ {}^o\text{F lb}^{.8}}$

f (T) is plotted in Figure A-5. This relationship will be used later.

We will now analyze the analogy between heat and mass transfer. For the analogy to apply, $P_r = S_c$ or $S_c/P_r = \alpha/D$ (Lewis Number) = 1. This situation is often

encountered in gas mixtures. The Lewis number for a mixture of $H_2 - H_2O$ will be determined later for substantiation of this proposed method of analysis.

The following assumptions are made: (a) the partial-pressure difference within the boundary layer should be small contrasted to the average fluid pressure; (b) the flow and heat transfer are not influenced by the mass transfer which implies that the properties appearing in the heat transfer equation are practically the properties of fluid 2 (noncondensable). In summary, fluid 1 (condensable) should be in low concentration, and the temperature at the wall should not be much less than the saturation temperature of the condensable in the stream.

It is the purpose of this analysis to determine the ratio h_D/h by analogy between the heat and mass transfer. This quantity is required in the heat balance equation.

By definition:

$$h_D \equiv \frac{m_{1w} R_1 T}{P_{1w} - P_1}$$

(applicable when the temperature difference in the boundary layer is small contrasted to the absolute temperature)

$$h \equiv \frac{Q}{T_w - T}$$

In order to relate the ratio m_{o1}/m_2 to the concentration and partial pressure ratio (condensable to noncondensable), the following analysis is performed:

Assume perfect gas laws to hold for each constituent,

$$P_1 V_1 = W_1 R_1 T_1 \text{ and } P_2 V_2 = W_2 R_2 T_2$$

In terms of molecular weight and the universal gas constant $\mathcal{R}$,

$$P_1 V_1 = \frac{W_1}{M_1} \mathcal{R}_1 T_1 \text{ and } P_2 V_2 = \frac{W_2}{M_2} \mathcal{R}_2 T_2$$

M lb/mole
W lb

and $W/M = N$ (number of moles).

In a mixture $V_1 = V_2$, $T_1 = T_2$ then,

$$\frac{P_1}{P_2} = \frac{W_1 M_2}{M_1 W_2} = \frac{N_1}{N_2}$$

for inlet conditions

$$\frac{P_{o1}}{P_2} = \frac{m_{o1}}{m_2} \quad \frac{M_2}{M_1}$$

Example:

$$M_2 \ (H_2) = 2$$

$$M_1 \ (H_2O) = 18$$

and $m_{o1} = m_2$ then

$$\frac{P_{o1}}{P_2} = \frac{2}{18} = \frac{1}{9} = \frac{N_{o1}}{N_2}$$

Thus, for equal weight quantities of constituents 1 (H_2O) and 2 (H_2), the concentration of 1 can be considered small contrasted to 2.

We will now compute the Lewis Number

$$S_{c_{12}} = \frac{\mu_2}{\rho_2 \ D_{12}} = 1.18 \ \frac{\Omega_D}{\Omega_V} \quad \frac{\sigma_{12}}{\sigma_2}^2 \left(\frac{M_1}{M_1 + M_2} \right) \quad \text{(Reference 28)}$$

Example:

Assume T = 300°F, 760°R, 422°K

(1) water vapor (2) hydrogen

$\sigma_2 = 2.968$ A $\qquad \epsilon_2/K = 33.3°K$

$\sigma_1 = 2.649$ A $\qquad \epsilon_1/K = 356°K$

$$\sigma_{12} = \frac{1}{2} \ (2.968 + 2.649) = 2.808$$

Note: $\left(\frac{\epsilon_2}{K} \ \frac{\epsilon_1}{K} \right)^{\frac{1}{2}} = \frac{\sqrt{\epsilon_2 \ \epsilon_1}}{K} =$

$$\frac{\epsilon_{12}}{K} = 1.09 \times 10^2$$

$$\epsilon_{12} = \sqrt{\epsilon_1 \ \epsilon_2}; \quad \frac{K T}{\epsilon_{12}} = \frac{K T}{\sqrt{\epsilon_1 \ \epsilon_2}}$$

$$\therefore \frac{K T}{\epsilon_{12}} = \frac{422}{1.09 \times 10^2} = 3.88$$

$\Omega_D = .89$, $M_1 = 18$ and $M_2 = 2$ (Reference 28)

$$\frac{KT}{\epsilon_2} = \frac{422}{33.3} = 12.7$$

$$\Omega_v = .8023 \text{ (Reference 28)}$$

$$Sc_{12} = 1.18 \; \frac{.89}{.8023} \left(\frac{2.808}{2.968}\right)^2 \left(\frac{18}{18+2}\right)^{1/2}$$

$$Sc_{12} = 1.18 \times 1.11 \times .895 \times .948 = 1.11$$

Computing the Lewis Number:

$$\frac{Sc_{12}}{Pr_2} = \frac{1.11}{.686} = 1.62 = \frac{\alpha_2}{D_{12}} = \text{Lewis Number}$$

$$D_{12} = \frac{\alpha}{1.62} = \frac{11 \text{ ft}^2/\text{hr}}{1.62} = 6.8 \text{ ft}^2/\text{hr} = 1.89 \times 10^{-3} \text{ ft}^2/\text{sec}$$

The Lewis Number is not far from 1, therefore, the analogy between heat and mass transfer should be applicable. Another consideration is to compute the Pr number for the mixture.

Based on the analogy between heat and mass transfer, the following relationships are assumed:

$$Nu = C \; Re^a Pr^b \tag{A-22}$$

$$\Lambda = C \; Re^a Sc^b$$

where Λ is the dimensionless mass transfer coefficient

$$\Lambda = \frac{h_D l}{D_{12}} \qquad Nu = \frac{h_D l}{k}$$

Dividing (A-23) by (A-22)

$$\frac{\Lambda}{Nu} = \left(\frac{Sc_{12}}{Pr}\right)^b$$

$$\frac{h_D k}{D_{12} h} = \left(\frac{Sc_{12}}{Pr}\right)^b$$

$$h_D/h = D_{12}/k \left(\frac{Sc_{12}}{Pr}\right)^b = \frac{D_{12}}{k} \quad (Le)^b$$

Since $\alpha = k/\rho c$ we can also write:

$$\frac{h_D}{h} = \frac{D_{12}}{\alpha \rho c} \quad (Le)^b = \left(\frac{L_e}{\rho c}\right)^{b-1}$$

or, in terms of properties,

$$\frac{h_D}{h} = \left(\frac{k}{\rho c \, D_{12}}\right)^{b-1} \frac{1}{\rho c} = \left(\frac{k}{D_{12}}\right)^{b-1} \frac{1}{(\rho c)^b} \left(\frac{D_{12}}{k}\right)^{1-b} \frac{1}{(\rho c)^b}$$

It is recommended that mixture properties be used for k , ρ and c for greater accuracy. The properties comprising h_D/h may be computed as follows:

Diffusion coefficients:

$$D_{12} = \frac{1.858 \times 10^{-3} \, T^{\frac{3}{2}} \left[\frac{M_1 + M_2}{M_1 \, M_2}\right]^{\frac{1}{2}}}{P_m \quad \sigma_{12}^2 \, \Omega_D} \qquad \text{(Reference 28)}$$

where

$$\sigma_{12} = \frac{1}{2} \, (\sigma_1 + \sigma_2) \qquad \sigma_1 \, (H_2O) = 2.649; \; \sigma_2 \, (H_2) = 2.968$$

$$\Omega_D = f \, (KT/\epsilon_{12}) \qquad \text{(Reference 28)}$$

$$\epsilon_{12} = \sqrt{\epsilon_1 \, \epsilon_2}$$

finding

$$\frac{\epsilon_1}{K} \; \& \; \frac{\epsilon_2}{K} \qquad \text{(Reference 28)}$$

since

$$\left(\frac{\epsilon_1}{K} \times \frac{\epsilon_2}{K}\right)^{\frac{1}{2}} = \frac{\sqrt{\epsilon_1 \, \epsilon_2}}{K} = \frac{\epsilon_{12}}{K}$$

Compute (ρ c) for a mixture of constituents 1 and 2,

$$(\rho \, c)_m = C_m \quad \text{(volumetric heat capacity) Btu/ft}^3\text{-}^\circ\text{F}$$

$$C_m = C_1 + C_2$$

$$C_m = \frac{P_1 C}{R_1 T} + \frac{P_2 C_2}{R_2 T}$$

(both constituents 1 and 2 occupy the same volume, therefore, the volumetric heat capacity is obtained by addition of the heat capacity of each)

also

$$P_m = P_1 + P_2$$

$$(\rho c)_m = \frac{P_1 C_1}{R_1 T} + \frac{(P_m - P_1) C_2}{R_2 T} = \frac{P_1 C_1}{R_1 T} + \frac{P_m C_2}{R_2 T} - \frac{P_1 C_2}{R_2 T}$$

$$(\rho c)_m = \frac{P_1}{T} \left(\frac{C_1}{R_1} - \frac{C_2}{R_2} \right) + \frac{P_m C_2}{R_2 T}$$

$$(\rho c)_m = \frac{P_m}{T} \left[\frac{P_1}{P_m} \left(\frac{C_1}{R} - \frac{C_2}{R} \right) + \frac{C_2}{R_2} \right]$$

Note that $\mathbf{R} = R_1 M_1 = R_2 M_2$

$$(\rho c)_m = \frac{P_m}{T} \left[\frac{P_1}{P_m} \left(\frac{C_1 M_1}{\mathbf{R}} - \frac{C_2 M_2}{\mathbf{R}} \right) + \frac{C_2 M_2}{\mathbf{R}} \right]$$

$$C_1 M_1 \equiv C_1^*$$

$$C_2 M_2 \equiv C_2^*$$

$$(\rho c)_m = \frac{P_m}{T\mathbf{R}} \left[\frac{P_1}{P_m} (C_1^* - C_2^*) + C_2^* \right]$$

Note:

$C_2^* = 7$ diatomic gases (H_2)

$C_1^* = 8$ triatomic gases (H_2O)

For $H_2(2)$, $H_2O(1)$ mixture

$$(\rho c)_m = \frac{P_m}{T\mathbf{R}} \left[\frac{P_1}{P_m} (8 - 7) + 7 \right] = \frac{P_m}{T\mathbf{R}} \left(\frac{P_1}{P_m} + 7 \right)$$

In summary, to compute h_D/h use

$$h_D/h = \left(\frac{D_{12}}{k}\right)^{1-b} \frac{1}{(\rho c)^b} \qquad \text{(A-24)}$$

insert mixture properties for ρ, c and k using

$$\rho c = \frac{P_m}{T R}\left[\frac{P_1}{P_m}\left(C_1^* - C_2^*\right) + C_2^*\right]$$

$$2 k = \frac{P_1}{P_m}\left(k_1 - k_2\right) + k_2 + \left[\frac{P_1}{P_m}\left(\frac{1}{k_1} - \frac{1}{k_2}\right) + \frac{1}{k_2}\right]^{-1}$$

$$D_{12} = \left[\frac{1.858 \times 10^{-3}\, T^{3/2}}{P_m\, \sigma_{12}^2\, \Omega_D}\right]\left[\left(\frac{M_1 + M_2}{M_1\, M_2}\right)^{\frac{1}{2}}\right]$$

where $\Omega_D = f\,(T)$ see Figure A-6.

Figure A-7 shows equation (A-24) plotted as a function of P_m and temperature at saturation.

We will now combine the heat and mass transfer considerations.

The mass transfer to the wall due to condensation of component 1 when T_w is below the dew point of 1 is given by

$$m_{1w} = \frac{h_D}{R_1 T}\left(P_1 - P_{1w}\right) \qquad \text{(A-25)}$$

(Note: perfect gas assumed)

The latent heat transfer associated with the mass transfer can, therefore, be expressed as

$$Q_{fv1} = m_{1w}\, h_{fv1} = \frac{h_D\, h_{fv1}}{R_1\, T}\left(P_1 - P_{1w}\right)$$

The sensible heat transfer portion of the total heat transfer is

$$Q_s = h\,(T - T_w)$$

Adding the two gives

$$Q = Q_{fv1} + Q_s = h\,(T - T_w) + \frac{h_D\, h_{fv1}}{R_1\, T}\left(P_1 - P_{1w}\right)$$

$$Q = h\,(T - T_w)\left[1 + \frac{h_D\, h_{fv1}}{h\, R_1\, T} \quad \frac{(P_1 - P_{1w})}{(T - T_w)}\right] \qquad \text{(A-26)}$$

The ratio h_D/h can be determined from the analogy between the heat and mass transfer mechanism. This analogy applies if component 1 is in low concentration in component 2.

If the partial pressure difference between the stream and wall is not too great as a result of the temperature difference being small when compared to the absolute temperature, then the expression,

$$(P_1 - P_{1w})/(T - T_w)$$

in (A-26) can be made equal to dP_1/dT by utilizing the Clapyeron equation as follows:

$$\frac{P_1 - P_{1w}}{T - T_w} = \frac{dP_1}{dT} = \frac{P_1\, h_{fv1}\, J}{R_1\, T^2} \qquad \text{(A-27)}$$

Combining equations (A-26) and (A-27):

$$Q = h\,(T - T_w)\left[1 + \left(\frac{h_D}{h}\right) \frac{h_{fv1}}{R_1\, T} \quad \frac{P_1 h_{fv1}\, J}{R_1\, T^2}\right]$$

$$= h\,(T - T_w)\left[1 + \left(\frac{h_D}{h}\right) \frac{h_{fv1}^{\,2}\, J}{R^2\, T^3}\right]$$

$$= h\,(T - T_w)\left[1 + \left(\frac{h_D}{h}\right) F\,(T)\right]$$

$$F(T) = \frac{h_{fv1}^{\,2}\, P_1\, J}{R_1^{\,2}\, T^3}$$

$$= \frac{(778)\,(144)}{85.7^2} \quad \frac{h_{fv1}^{\,2}\, P_1}{T^3}$$

$$= 15.25\, \frac{h_{fv1}^{\,2}\, P_1}{T^3}$$

where:

h_{fvl} is in Btu/lb

P_1 is in lb/in^2

T is in ^{o}R

F(T) is in Btu/ft^3-^{o}R

Figure A-8 shows F (T) plotted as a function of P_m and T at saturation. It can be seen from Figures A-7 and A-8 that

$$\frac{h_D}{h} \; F\,(T) \gg\gg 1$$

so:

$$Q = h\left(\frac{h_D}{h}\right) F\,(T)\,(T - T_w)$$

$$= \frac{1}{60}\;\frac{G_2^{\,.8}}{D^{.2}}\quad f\,(T)\left(\frac{h_D}{h}\right) F\,(T)\,(T - T_w)$$

$$= \frac{1}{60}\;\frac{G_2^{\,.8}}{D^{.2}}\quad \bar{F}\,(T)\quad \Delta\,T$$

where:

Q is in Btu/hr-ft^2

G is in lb/ft^2-hr

D is in ft

$\bar{F}$ (T) is in Btu/hr-ft^2-^{o}F

ΔT is in ^{o}R

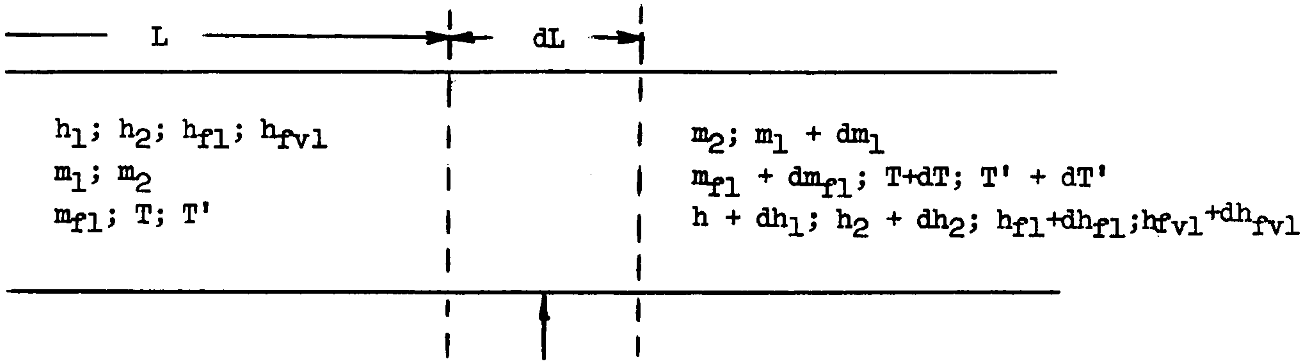
$\bar{F}$ (T) is plotted in Figure A-9 as a function of P_m and T at saturation.

Substituting representative values of G and D in the above equation for Q results in combined coefficients of 1000-2000 Btu/hr-ft^2-^{o}F. Since this high a value of combined h will have small resistance to heat flow when compared to the wall and radiation resistance, its value will be taken as constant at 1000 Btu/hr-ft^2-^{o}F and not entered in the programs as a function of P_m and T.

APPENDIX A-5

HEAT LOSS ANALYSIS OF A TWO-COMPONENT MIXTURE

Examine a small section of a tube in which a two-component mixture at the saturation temperature of one of the components is flowing:



Note: The prime denotes superheated state, i.e., T' - T = superheat.

Notation:

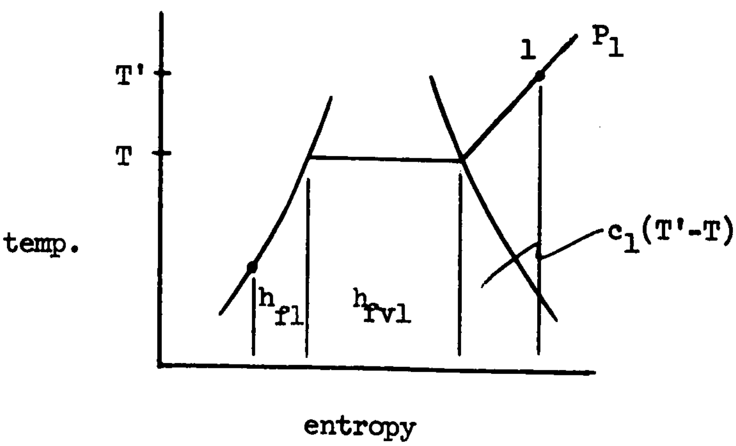
Subscript 1 refers to the condensable phase (vapor).
Subscript f1 refers to the liquid phase of 1.
Subscript 2 refers to the noncondensable phase (gas).

Energy Balance:

$$h_1 m_1 + h_2 m_2 + h_{f1}\, m_{f1} + dq = m_2\,(h_2 + dh_2) + (m_1 + dm_1)$$

$$(h_1 + dh_1) + (m_{f1} + dm_{f1})\,(h_{f1} + dh_{f1})$$

$$dq = m_2\, dh_2 + m_1\, dh_1 + h_1\, dm_1 + m_{f1}\, dh_{f1} + h_{f1}\, dm_{f1}$$



$$h_1 = c_1(T' - T) + h_{fv1} + h_{f1}$$

$$h_1 = c_1(T' - T) + h_{fv1} + c_{f1}\,(T-T_R)$$

$$dh_1 = c_1\,(dT' - dT) + dh_{fv1} + c_{f1}\, dT$$

Mass Balance:

$$m_2 = \text{constant}$$

$$m_1 + m_{f1} = m_{o1} = \text{constant}$$

$$dm_1 = - dm_{f1}$$

combining mass and heat balance gives

$$dq = m_2 dh_2 + m_1 dh_1 + h_1 dm_1 + (m_{o1} - m_1)\, dh_{f1} - h_{f1}\, dm_1$$

$$dq = m_2 dh_2 + m_1 dh_1 + (h_1 - h_{f1})\, dm_1 + (m_{o1} - m_1)\, dh_{f1} \qquad \text{(A-28)}$$

$$h_1 = c_1 (T' - T) + h_{fv1} + h_{f1}$$

and

$$dh_1 = c_1 (dT' - dT) + dh_{fv1} + dh_{f1}$$

also

$$dh_2 = c_2\, dT'$$

substituting these into (A-28) we have

$$dq = m_2 c_2 dT' + m_1 c_1 (dT' - dT) + m_1 dh_{fv1} + m_1 dh_{f1} + c_1 (T' - T)$$
$$dm_1 + h_{fv1}\, dm_1 + (m_{o1} - m_1)\, dh_{f1}$$

and

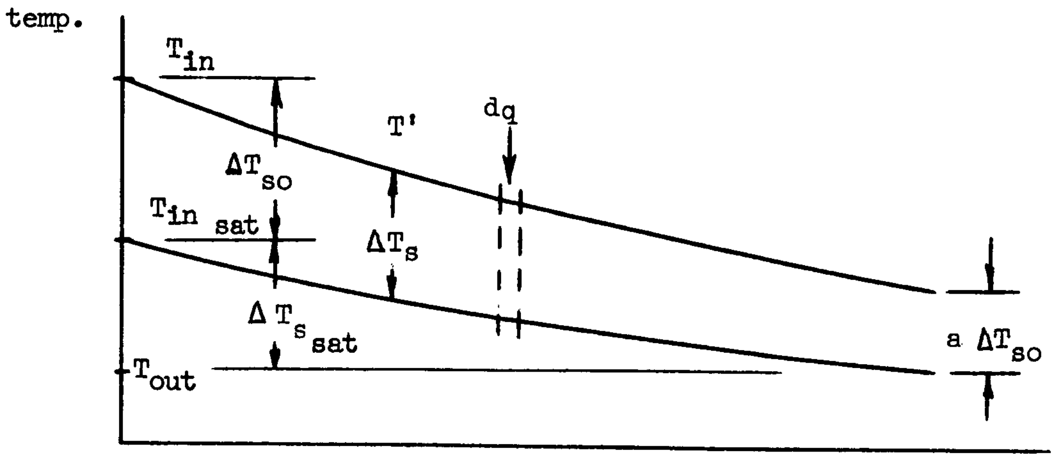
$$m_2 c_2\, dT' = m_2\, c_2\, dT' - m_2 c_2\, dT + m_2 c_2\, dT =$$

$$\left[m_2 c_2 + m_2 c_2 \frac{d\,(T' - T)}{dT} \right] dT$$

$$dq = \left\{ m_2 c_2 + m_{o1}\ c_{f1} + m_2 c_2 \frac{d\,(T' - T)}{dT} + \frac{d\left[m_1 c_1\,(T' - T)\right]}{dT} \right\} dT +$$
$$h_{fv1}\, dm_1 + m_1\, dh_{fv1}$$

$$dq = \left\{ m_2 c_2 \left(1 + \frac{d\,(T' - T)}{dT}\right) + m_{o1}\ c_{f1}\ \left(1 + \frac{d\left[m_1 c_1 (T' - T)\right]}{m_o\ c_{f1} dT}\right) \right\} dT +$$
$$h_{fv1}\, dm_1 + m_1\, dh_{fv1}$$

Let $T' - T = \Delta T_s$



$$dq = \left\{ m_2 c_2 \left(1 + \frac{d\ \Delta T_s}{dT}\right) + m_{ol}\ c_{fl} \left(1 + \frac{d\ \left[m_1 c_1\ \Delta T_s\right]}{m_{ol}\ c_{fl}\ dT}\right) \right\} dT +$$

$$h_{fvl}\ dm_1 + m_1\ dh_{fvl}$$

Let

$$\frac{d\ \Delta T_s}{d\ T} = (1 - a)\ \frac{\Delta T_{so}}{\Delta T} \quad \text{and}\ d\ \frac{\left[m_1 c_1\ \Delta T_s\right]}{d\ T} = m_{ol}\ c_1\ \frac{\Delta T_{so}}{\Delta T}$$

$$\left[1 - a \left(\frac{m_{el}}{m_{ol}} \right)\right]$$

Therefore,

$$dq = \left\{ m_2 c_2 \left(1 + \left[1 - a\right] \frac{\Delta T_{so}}{\Delta T}\right) + m_{ol}\ c_{fl} \left(1 + \frac{c_1}{c_{fl}} \left[1 - \left(\frac{m_{el}}{m_{ol}} \right) a\right] \right.\right.$$

$$\left.\left. \frac{\Delta T_{so}}{\Delta T} \right) \right\} dT + h_{fvl}\ dm_1 + m_1\ dh_{fvl}$$

define

$$\beta_2 \equiv 1 + (1 - a)\ \frac{\Delta T_{so}}{\Delta T}$$

$$\beta_1 \equiv 1 + \frac{c_1}{c_{fl}} \left[(1) - (a)\ \frac{m_{el}}{m_{ol}}\right] \frac{\Delta T_{so}}{\Delta T}$$

The assumption is made in the programs that a = o (saturated outlet). Then:

$$\beta_2 = 1 + \frac{\Delta T_{so}}{\Delta T}$$

$$\beta_1 = 1 + \left(\frac{c_1}{c_{f1}}\right) \frac{\Delta T_{so}}{\Delta T}$$

and the heat balance becomes

$$dq = (m_2 c_2 \beta_2 + m_{o1} c_{f1} \beta_1) dT + h_{fv1} \quad dm_1 \quad + m_1 \, dh_{fv1} \qquad \text{(A-29)}$$

The amount of saturated phase 1 contained in component 2 depends on the temperature level. Thus m_1/m_2 is a function of the temperature. This relationship can be established by the equations of state. Assuming perfect gases for constituents 1 and 2, we have

$$\frac{m_1}{m_2} = \frac{P_1 V_1 \; R_2 T_2}{R_1 T_1 \; P_2 V_2}$$

In a gaseous mixture in thermal equilibrium $T_1 = T_2$, $V_1 = V_2$ and by Dalton's Law of partial pressures $P_m = P_1 + P_2$, therefore, we obtain

$$\frac{m_1}{m_2} = \frac{R_2}{R_1} \frac{P_1}{P_2} = \frac{R_2}{R_1} \frac{P_1}{(P_m - P_1)} \qquad \text{(A-30)}$$

where P_1 is a function of T for saturated conditions of component 1. Thus

$$\frac{m_1}{m_2} = f\,(T)$$

In order to combine (A-29) and (A-30) differentiate (A-30) as follows:

$$m_1 \, (P_m - P_1) = (m_2 \frac{R_2}{R_1}) \, P_1$$

$$dm_1 = m_2 \frac{R_2}{R_1} \frac{P_m \, dP_1}{(P_m - P_1)^2} \qquad \text{(A-31)}$$

Combine (A-31) with (A-29) eliminating dm_1 and m_1

$$dq = (m_2 c_2 \beta_2 + m_{o1} c_{f1} \beta_1) dT + h_{fv1} \, m_2 \frac{R_2}{R_1} \frac{P_m \, dP_1}{(P_m - P_1)^2} +$$

$$m_2 \frac{R_2}{R_1} \left(\frac{P_1}{P_m - P_1} \right) d \, h_{fv1} \qquad \text{(A-32)}$$

The relationship between T and P_1 for saturated conditions for constituent 1 can be established by the Clapeyron relation, namely,

$$\frac{dP_1}{P_1} = \frac{h_{fv1}\ J}{R_1} \frac{dT}{T^2} \tag{A-33}$$

(Note: In this form of Clapeyron's relation, a perfect gas is assumed and also the specific volume of the liquid phase is neglected when contrasted to the specific volume of the vapor phase.)

Combining equations (A-32) and (A-33) and realizing that:

$$dh_{fv1} = \left(\frac{\partial h_{fv1}}{\partial T}\right)_{sat} dT$$

results in:

$$dq = dT \left\{ (m_2 c_2 \beta_2 + m_{o1}\ c_{f1} \beta_1) + m_2 \frac{R_2}{R_1} \frac{1}{\left(\frac{P_m}{P_1} - 1\right)} \left[\left(\frac{\partial h_{fv1}}{\partial T}\right)_{sat} + h_{fv1}^2 \frac{J}{R_1 T^2} \frac{P_m/P_1}{(P_m/P_1 - 1)} \right] \right\}$$

$$= \left[(m_2 c_2 \beta_2 + m_{o1}\ c_{f1} \beta_1) + m_2\ \mathfrak{f}\ (T) \right] dT \tag{A-34}$$

where

$$\mathfrak{f}\ (T) \equiv \frac{R_2}{R_1} \frac{1}{(P_m/P_1 - 1)} \left[\left(\frac{\partial h_{fv1}}{\partial T}\right)_{sat} + h_{fv1}^2 \frac{J}{R_1 T^2} \frac{P_m/P_1}{(P_m/P_1 - 1)} \right] \tag{A-35}$$

Evaluating $\left(\frac{\partial h_{fv1}}{\partial T}\right)_{sat}$ for water between 100 and 500°F

results in:

$$\left(\frac{\partial h_{fv1}}{\partial T}\right)_{sat} = -\frac{4360}{T^{1.38}} \qquad (T \text{ in } ^\circ R) \tag{A-36}$$

Combining equations (A-35) and (A-36) yields f (T) as a function of temperature and total pressure shown plotted in Figure A-10. By curve fitting:

$$\mathfrak{f}\ (T) = 41.9\ P_m^{-1.112}\ e^{.0237T}$$

since

$$q = \int_{T_{in}}^{T_{out}} dT \left[m_2 c_2 \beta_2 + m_{o1}\ c_{f1} \beta_1 + m_2\ \mathfrak{f}\ (T) \right]$$

$$q = (m_2 c_2 \beta_2 + m_{o1}\, c_{f1} \beta_1)(T_{in} - T_{out}) + m_2 \int_{T_{in}}^{T_{out}} 41.9\, P_m^{-1.112}\, e^{.0237T}\, dT$$

$$q = (m_2 c_2 \beta_2 + m_{o1}\, c_{f1}\, \beta_1)(T_{in} - T_{out}) - 1770\, m_2 P_m^{-1.112}$$

$$(e^{.0237\, T_{out}} - e^{.0237\, T_{in}}) \qquad \text{(A-37)}$$

where: q is in Btu/min

m is in lb/min

c is in Btu/lb-^{o}F

T is in ^{o}R

P is in lb/in^2-abs.

Equation (A-37) is included in simultaneous heat flow equations and represents the heat loss of a saturated hydrogen-water vapor mixture when cooled from T_{in} to T_{out}.

COMPARISON OF INTEGRATED VS. MID-POINT VALUES
OF FIN-TO-TUBE VIEW FACTORS FOR r/w = 1

Section See Figure 4	$F_{Integrated}$	$F_{At\ Mid\text{-}Point}$	% error
3 to 1	.359	.348	3.07
4 to 1	.2265	.2237	1.23
5 to 1	.1394	.1379	1.03
6 to 1	.0863	.0842	2.41
6 to 1'	.0552	.0547	.707
5 to 1'	.0405	.0401	.987
4 to 1'	.0331	.0330	.303
3 to 1'	.03010	.02961	1.63

NOTE: 1' refers to the adjacent tube.

Figure A-1

VIEW FACTORS FOR CENTRAL FIN

Section	View Factor to Both Tubes
3	$1 - \dfrac{\sqrt{.1\ (r/w) + .0025}}{2\ (r/w) + .1} - \dfrac{\sqrt{3.8025 + 3.9\ (r/w)}}{2\ (r/w) + 3.9}$
4	$1 - \dfrac{\sqrt{.4\ (r/w) + .04}}{2\ (r/w + .1} - \dfrac{\sqrt{3.24 + 3.6\ (r/w)}}{2\ (r/w) + 3.6}$
5	$1 - \dfrac{\sqrt{.9\ (r/w) + .2025}}{2\ (r/w) + .9} - \dfrac{\sqrt{2.4025 + 3.1\ (r/w)}}{2\ (r/w) + 3.1}$
6	$1 - \dfrac{\sqrt{1.6\ (r/w) + .64}}{2\ (r/w) + 1.6} - \dfrac{\sqrt{1.44 + 2.4\ (r/w)}}{2\ (r/w) + 2.4}$

View Factor Tube to Space $= \dfrac{2}{\pi}\left[1 + w/r\ \left(1 - \sqrt{(r/w) + 1}\right) + \dfrac{1}{2}\cos^{-1}\left(\dfrac{1}{1 + 2\ w/r}\right)\right]$

Figure A-2

VIEW FACTORS FOR OPEN AND CLOSED SANDWICH

Section	View Factor to Both Tubes
3	$1 - \frac{1}{2}\left[\frac{.1(r/w) + .0025}{.1(r/w) + .0025 + 2(r/w)^2} + \frac{3.8025 + 3.9(r/w)}{3.8025 + 3.9(r/w) + 2(r/w)^2}\right]$
4	$1 - \frac{1}{2}\left[\frac{.4(r/w) + .04}{.4(r/w) + .04 + 2(r/w)^2} + \frac{3.24 + 3.6(r/w)}{3.24 + 3.6(r/w) + 2(r/w)^2}\right]$
5	$1 - \frac{1}{2}\left[\frac{.9(r/w) + .2025}{.9(r/w) + .2025 + 2(r/w)^2} + \frac{2.4025 + 3.1(r/w)}{2.4025 + 3.1(r/w) + 2(r/w)^2}\right]$
6	$1 - \frac{1}{2}\left[\frac{1.6(r/w) + .64}{1.6(r/w) + .64 + 2(r/w)^2} + \frac{1.44 + 2.4(r/w)}{1.44 + 2.4(r/w) + 2(r/w)^2}\right]$

View Factor Tube to Space $= \frac{1}{\pi}\left[1 + \tan^{-1}(1 + 2\, w/r) - \pi/4\right]$

Figure A-3

LOCAL VIEW FACTOR TO SPACE -
TRIFORM AND CRUCIFORM CONFIGURATIONS

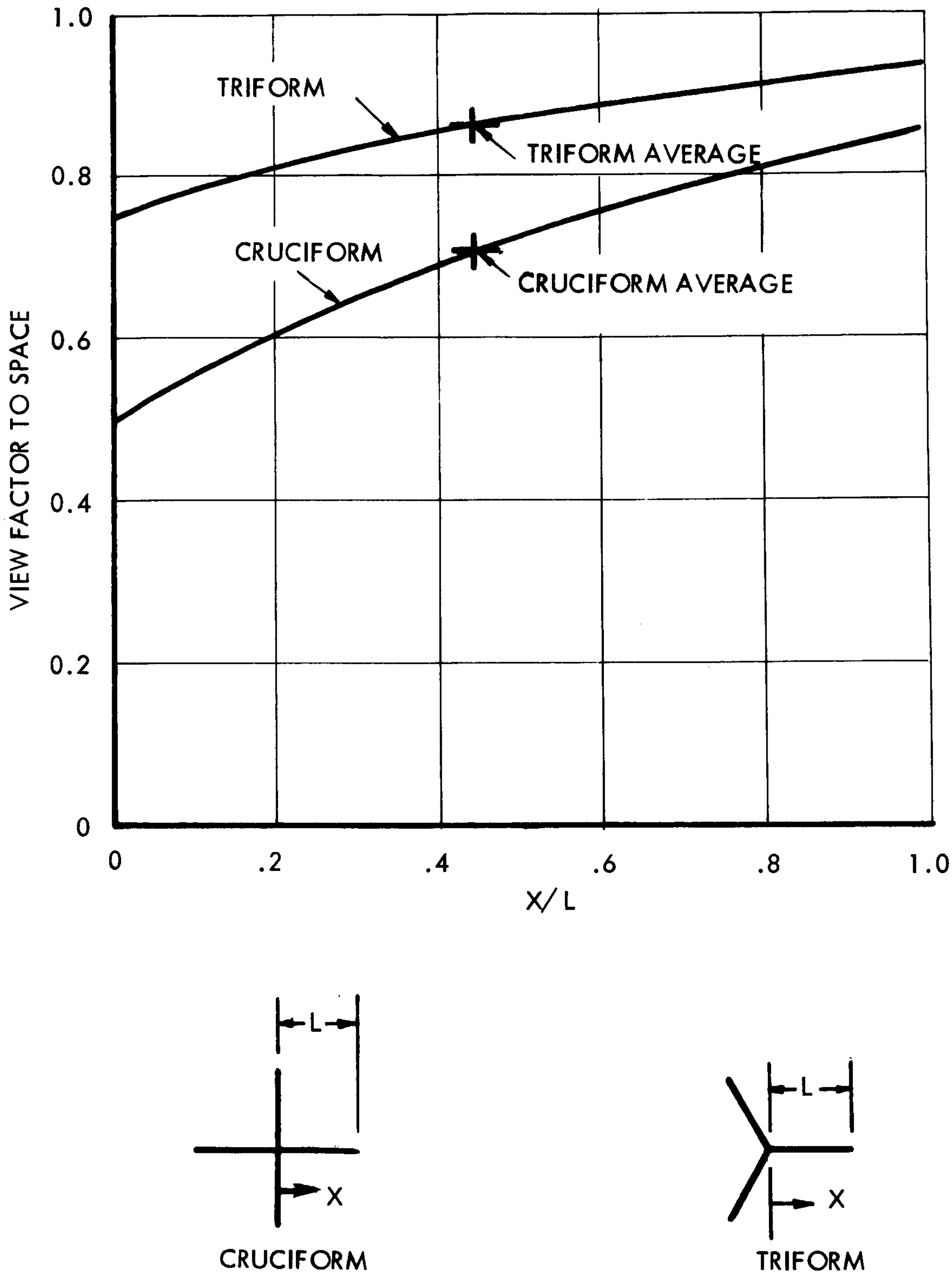


Figure A-4

f(T) VS. TEMPERATURE

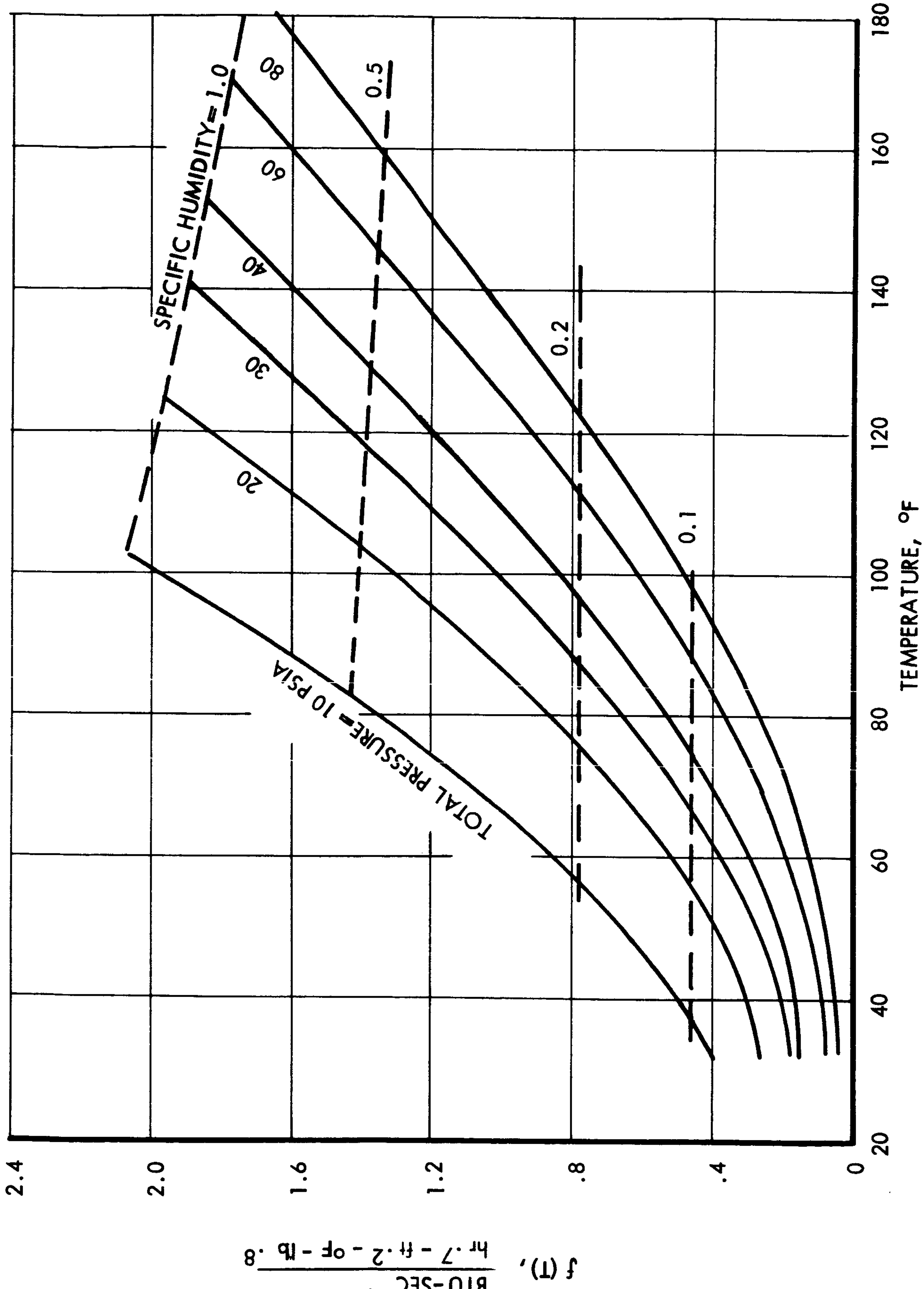


Figure A-5

VALUES OF THE COLLISION INTEGRAL, Ω_D, BASED ON THE LENNARD-JONES POTENTIAL
(Plotted from Values Obtained from Ref. 28)

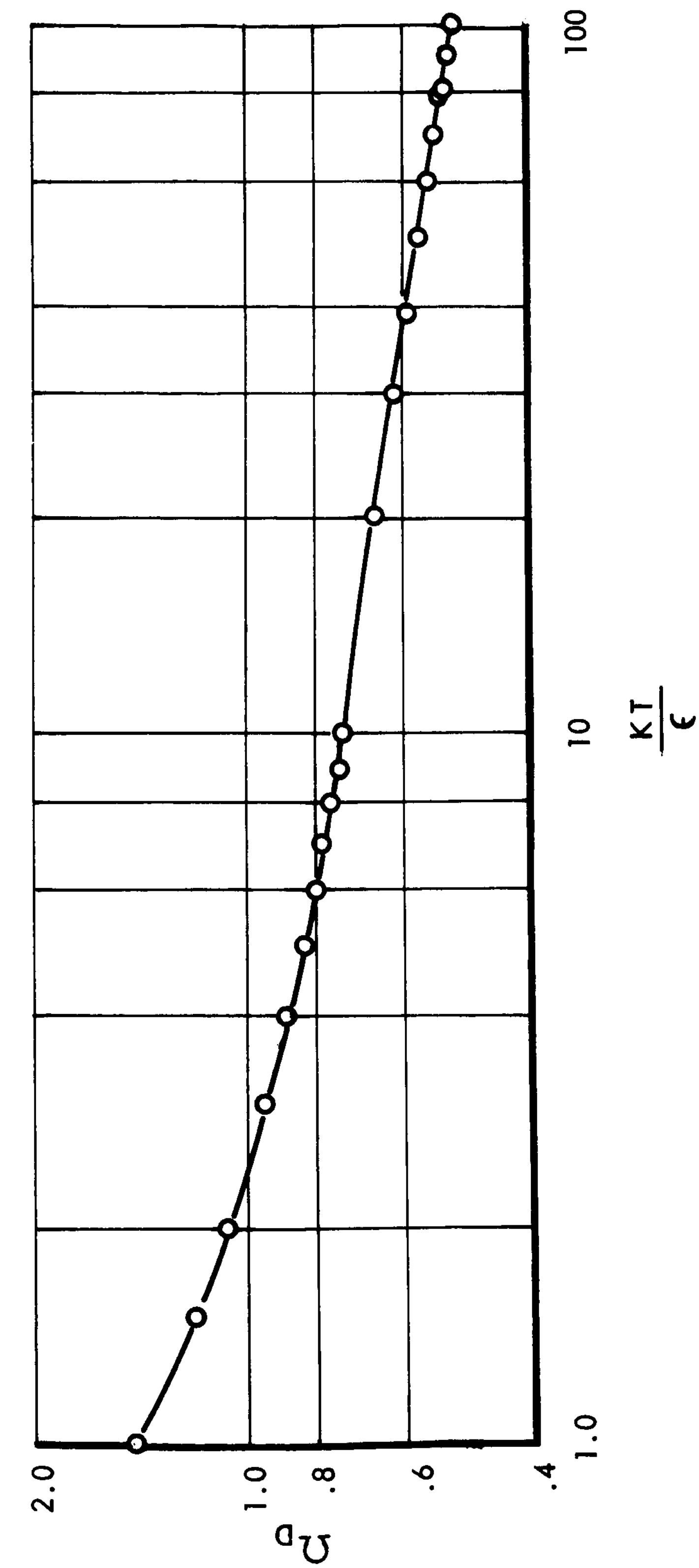


Figure A-6

h_D/h VS. TEMPERATURE

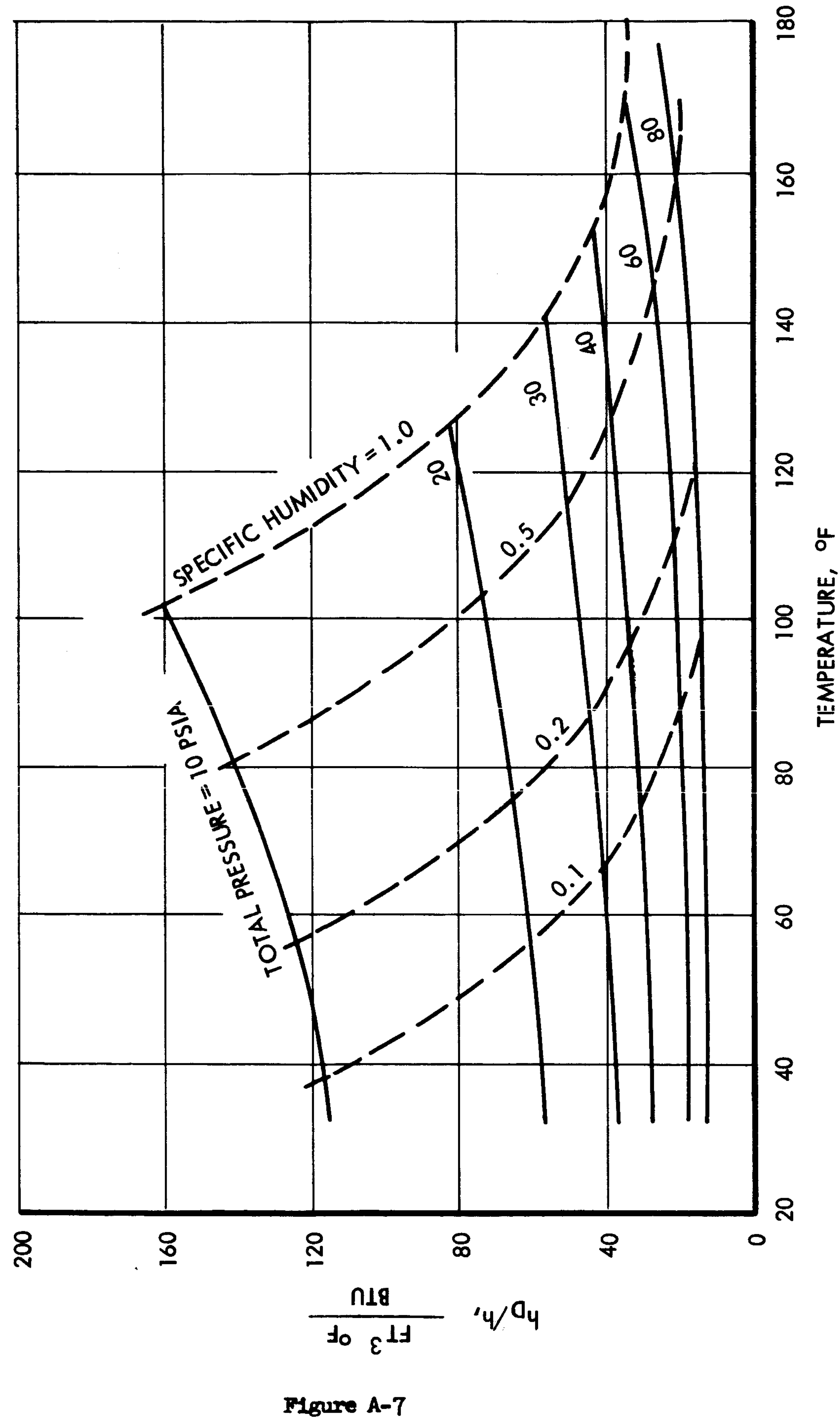


Figure A-7

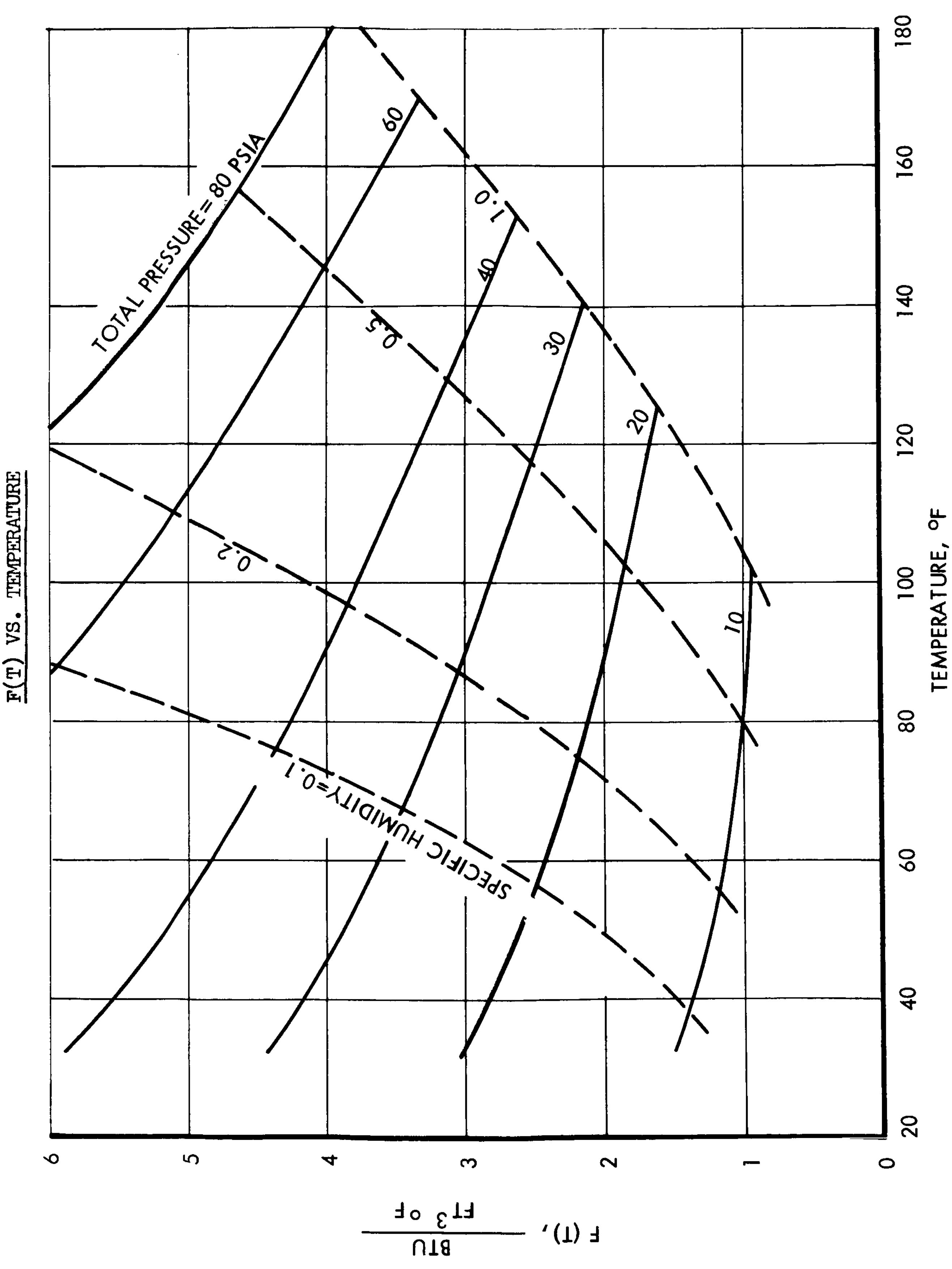

F(T) VS. TEMPERATURE
TOTAL PRESSURE=80 PSIA
SPECIFIC HUMIDITY=0.1
0.2
0.5
1.0
10
20
30
40
60
TEMPERATURE, °F
20
40
60
80
100
120
140
160
180
F(T), BTU/FT3 °F
0
1
2
3
4
5
6

Figure A-8

$\bar{F}(T)$ VS. TEMPERATURE

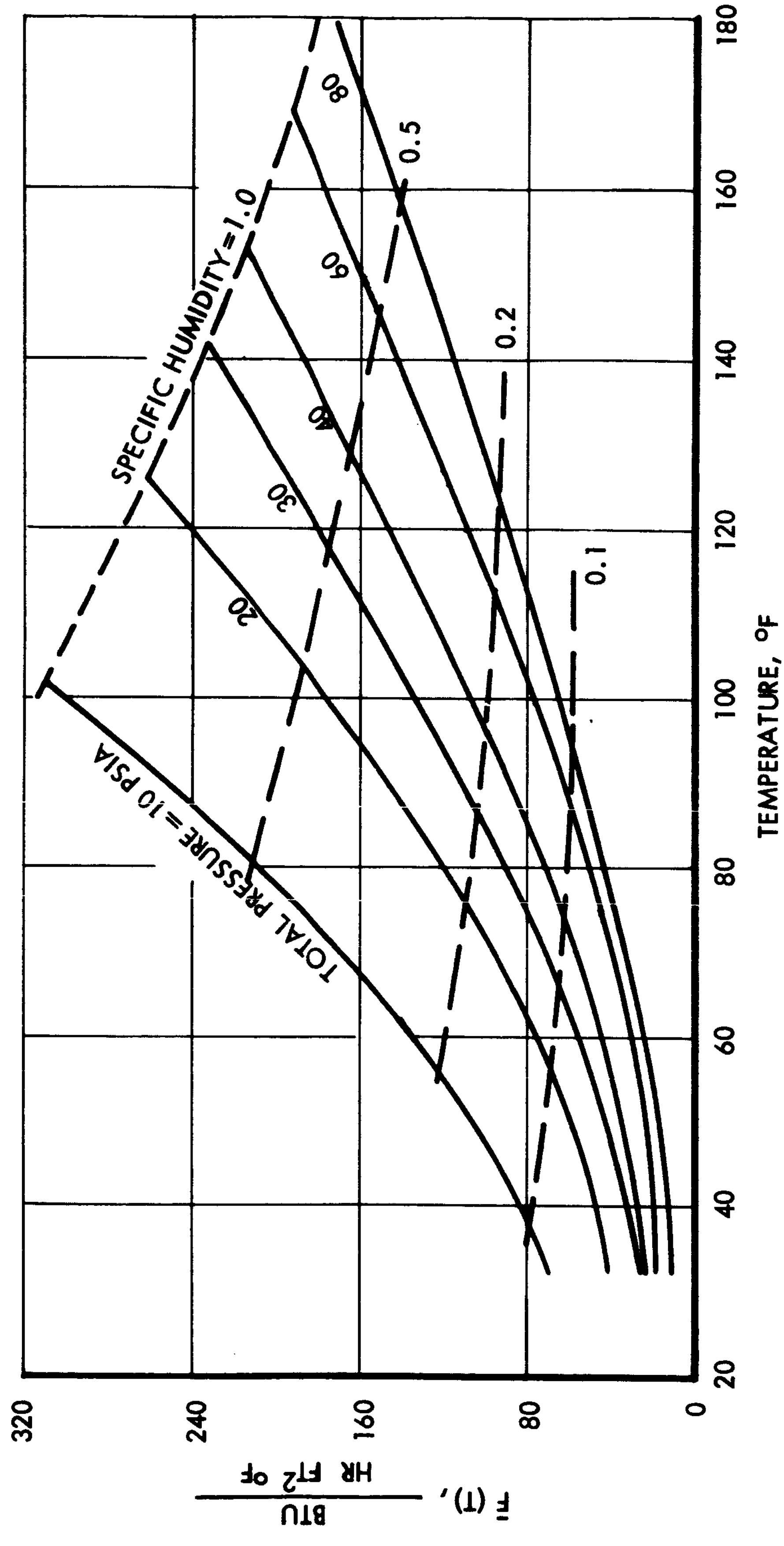


Figure A-9

$\mathcal{F}$(T) VS. TEMPERATURE

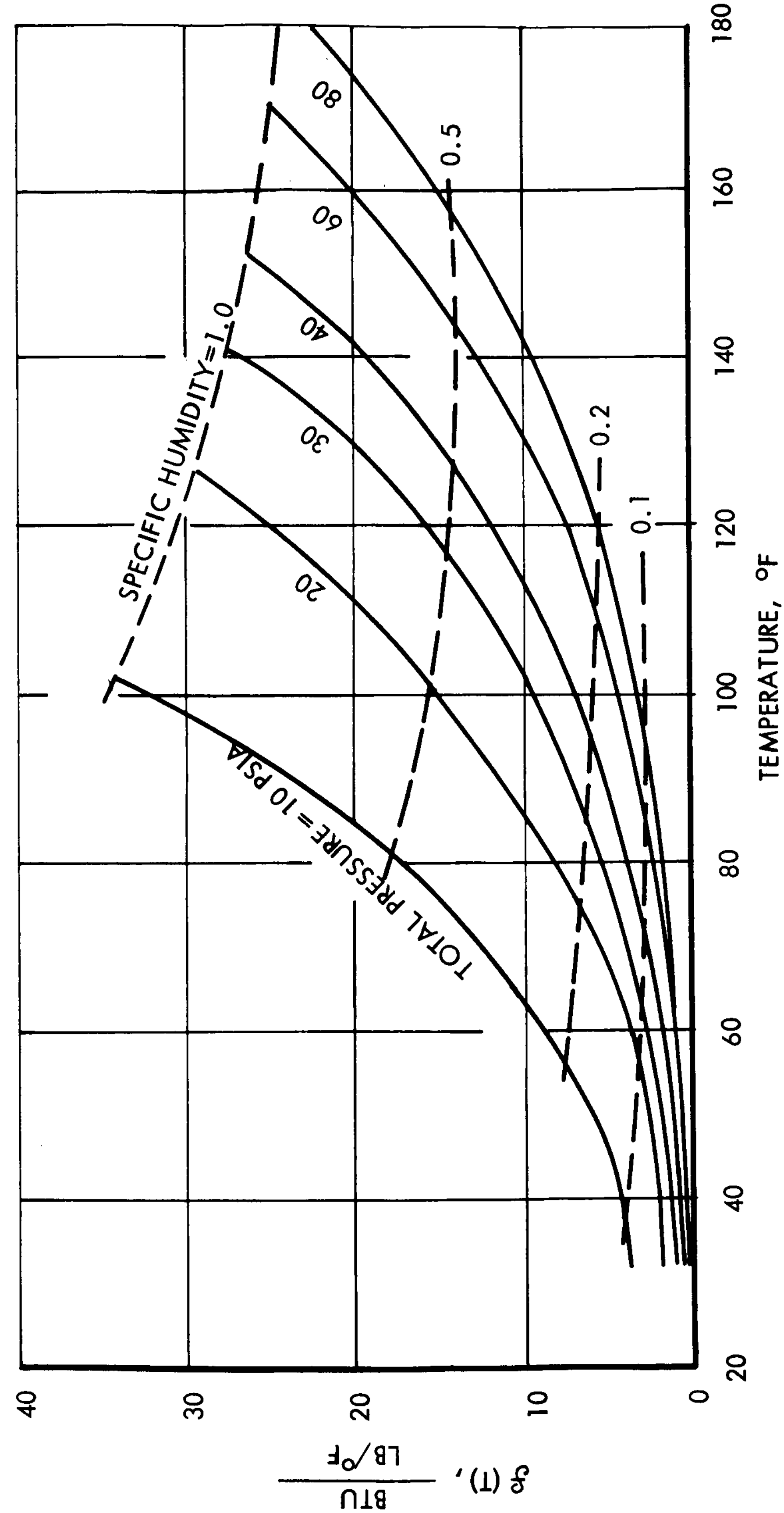


Figure A-10

APPENDIX B-1

FILM STABILITY ANALYSIS

Two types of film instabilities may affect the performance of space condenser-radiators. The first is known as the Kelvin-Helmholtz (inertia and surface tension) instability and the second is the Schlichting-Tollmien (inertia and viscosity) instability. Both are characterized by the breakup of a wall-bound film and transition from annular to fog flow (dispersed condensate) as shown in Figure B-1. (Figures for Appendix B can be found at the end of the Appendix.)

This appendix will determine which type of instability is likely to govern in space condensers and where it will occur. Knowledge of this transition point will enable a designer to intelligently apply two-phase pressure drop information to space condensers, i.e., annular flow correlations prior to film breakup and fog flow correlations subsequent to film breakup.

First examine the Kelvin-Helmholtz phenomena. Figure B-2 shows how the film Reynolds and Weber numbers vary with condensing length.

Knowledge of the maximum value of film Weber number could give some insight into the importance of this instability mode. Finding this maximum as a function of system inputs: (The nomenclature used in Appendix B is identical to that used in the Analytical Section, see Nomenclature Section.)

$$W_f = \frac{U_2^2 \rho_f \delta}{g_c \sigma}$$

$$\frac{U_2}{g_s \sigma} \left(U_2 \rho_f \delta \right) = W_f$$

Note that:

$$U_2 \rho_f \delta = 2 (1 - X) \frac{m_o}{\pi D} \quad \text{where } U \text{ (mean)} = \frac{U_2}{2}$$

and

$$U_2 = U_v \left(\rho_v / \rho_f \right)^{1/2} \quad \text{(momentum considerations)}$$

also

$$X m_o = \frac{\pi D^2}{4} \rho_v U_v$$

combining

$$\frac{U_v}{g_s \sigma} \left(\rho_v / \rho_f \right)^{1/2} \; 2 (1 - X) \frac{m_o}{\pi D} = W_f$$

$$\frac{X\, m_o}{\frac{\pi D^2}{4}\ \rho_v\, g_s\, \sigma}\ (\rho_v/\rho_f)^{1/2}\ 2(1 - X)\ \frac{m_o}{\pi D} = W_f$$

$$\frac{8\, m_o^{\,2}}{\pi^2\, \rho_v\, g_s\, \sigma}\ (\rho_v/\rho_f)^{1/2}\quad X\,(1 - X) = W_f\, D^3$$

Let $K = \dfrac{8\, m_o\ (\rho_v/\rho_f)^{1/2}}{\pi^2\ \rho_v\, g_s\, \sigma}$ (a constant)

Therefore, $K\, X\,(1 - X) = W_f\, D^3$ (B-1)

differentiating:

$$K\,(dX - 2\,X\,dX) = W_f\, 3\, D^2\, d\,D + D^3\, d\,W_f$$

$$K\,(1 - 2\,X) = W_f\, 3\, D^2\, d\,D/dX + D^3\ d\,W_f/dX$$

Setting

$$\frac{dW_f}{dX} = 0$$

$$\frac{dX}{dD}\ \frac{K\,(1 - 2X)}{3\, D^2} = W_{f_{max}} \tag{B-2}$$

Also note that

$$\frac{\pi D_o^{\,2}}{4}\ \rho_v\, U_{v_o} = m_o$$

Therefore,

$$K = \frac{8}{\pi^2 \rho_v\, g_s\, \sigma}\ (\rho_v/\rho_f)^{1/2}\ \frac{\pi^2\, D_o^{\,4}\, \rho_v^{\,2}\, U_{v_o}}{16}$$

$$K = D_o^{\,3}\ \frac{D_o\ \rho_v\, U_{v_o}^{\,2}}{2\, g_s\, \sigma}\quad (\rho_v/\rho_f)^{1/2}$$

$$K = D_o^{\,3}\, W_{v_o}\ (\rho_v/\rho_f)^{1/2}\quad \text{where } W_{v_o} \equiv \frac{D_o\ \rho_v\, U_{v_o}^{\,2}}{2\, g_s\, \sigma} \tag{B-3}$$

recalling that

$$W_f = \frac{KX}{D^3} \quad (1 - X)$$

We can now define the point of maximum W_f in terms of X and D, therefore,

$$dX/dD \quad \frac{K\ (1 - 2X)}{3\ D^2} = \frac{KX}{D^3} \quad (1 - X)$$

or

$$\frac{1 - 2X}{X(1 - X)} = \frac{3}{D} \quad \frac{dD}{dX} \tag{B-4}$$

for a constant diameter tube dD/dX = 0 and X = 1/2. Therefore,

$$W_{f_{max}} = \frac{KX\ (1 - X)}{D^3} = \frac{K\ 1/2}{D_o^{\ 3}} \quad (1 - 1/2) = \frac{K}{4\ D_o^{\ 3}}$$

$$W_{f_{max}} = \frac{D_o^{\ 3} \quad W_{v_o}}{4\ D_o^{\ 3}} \quad (\rho_v/\rho_f)^{1/2} = \frac{W_{v_o}}{4} \ (\rho_v/\rho_f)^{1/2} \tag{B-5}$$

Generalizing at neutral stability, L_n, W_f = 3 (from reference 20) and by equation (B-2)

$$\frac{dX}{dD} \quad \frac{K}{3\ D^2} \quad (1 - 2X) = 3 \tag{B-6}$$

Each term (X, D) in equation (B-6) can be expressed in terms of L, thus giving L = function of K.

$$\left\{ \frac{dX}{dD} \quad \underbrace{\frac{(1 - 2X)}{D^2}}_{\text{function of L}} \right\} \frac{D_o^{\ 3}}{3} \ W_{v_o} \quad (\rho_v/\rho_f)^{1/2} = 3 \tag{B-7}$$

Solve (B-7) for L_n

Note: For a constant diameter tube use (B-5) to give W_{vo} necessary to give an instability at X = 1/2 or L_n/L_c = 1/2, namely,

$$12 = W_{v_o} \ (\rho_v/\rho_f)^{1/2}$$

Example: $(\rho_f/\rho_v)^{1/2}$ = 30 (water)

W_{v_o} = 360 (minimum for instability)

Under normal conditions, W_{f_n} will occur before the point of maximum W_f then use equation (B-1)

$$KX(1 - X) = W_f D^3$$

$$\frac{D_o^3 W_{v_o}}{W_{f_n}} (\rho_v/\rho_f)^{1/2} = \frac{D^3}{X(1 - X)} \qquad \text{(B-8)}$$

where the right hand term is a function of L.

Let $W_{f_n} = 3$ (again from reference 20) assume $D = D_o$

$$1 - X_n = L_n/L_c$$

then (B-8) becomes

$$\frac{W_{v_o}}{3} (\rho_v/\rho_f)^{1/2} = \frac{1}{L_n/L_c \; (1 - L_n/L_c)}$$

$$(L_n/L_c)^2 - (L_n/L_c) + \frac{3}{W_{v_o}} (\rho_f/\rho_v)^{1/2} = 0$$

by quadratic formula

$$L_n/L_c = \frac{1 \pm \sqrt{1 - 4\,(1)\,(3/W_{v_o})\,(\rho_f/\rho_v)^{1/2}}}{2}$$

$$= \frac{1 \pm \sqrt{1 - (12/W_{v_o})\,(\rho_f/\rho_v)^{1/2}}}{2}$$

Let $(\rho_f/\rho_v)^{1/2} = 30$ (water) and plot W_{v_o} versus L_n/L_c (Figure B-3).

This shows that for some values of inlet vapor Weber number, no Kelvin-Helmholtz instability exists.

Turning now to the Schlichting-Tollmien instability:

$$R_f \quad \frac{\delta \rho_f U_2}{\mu_f} = \frac{2(1 - X)\,m_o}{\pi D \mu_f}$$

$$R_{f_n} = 200 \text{ (from reference 20)}$$

then

$$\frac{200 \pi \mu_f}{2 m_o} = \frac{1 - X}{D}$$

$$\frac{100\,\pi\,\mu_f}{\frac{\pi\,D_o^{\,2}}{4}\,\rho_v U_{v_o}} = \frac{1 - X}{D}$$

or

$$\frac{400}{D_o}\,(\mu_f/\mu_v)\,\frac{1}{R_{v_o}} = \frac{1 - X}{D} \qquad \text{(B-9)}$$

The right hand term (1 - X/D) is a function of L and (B-9) will, therefore, give $L = L_n$. For a constant diameter tube and X varying linearly with L, we obtain

$$400\,(\mu_f/\mu_v)\,1/R_{v_o} = 1 - X = L_n/L_c$$

using $\mu_f/\mu_v = 50$ (water), plot R_{v_o} versus L_n/L_c (Figure B-4).

Again, as with the Kelvin-Helmholtz phenomena, the Schlichting-Tollmien instability may never occur in a condenser.

In summary, neutral stability is defined by

$$\gamma(W_{f_n}, R_{f_n}) = 0$$

A sufficient condition for stability is

$$W_f < 3 \quad \text{(Kelvin-Helmholtz) and}$$
$$R_f < 200 \quad \text{(Schlichting-Tollmien)}$$

which is conservative and the condition assumed in this analysis.

APPENDIX B-2

DETERMINATION OF L^*/L_n

Investigating film growth rate starting with the wave growth equation:

$$\frac{dB}{B} = \alpha_{ci} \frac{U_2}{\delta} \, d\theta \quad \text{(from reference 21)} \tag{B-10}$$

Wave propagation equation

$$dL = U_2 \left(\frac{C_R}{U_2} + 1 \right) d\theta + \theta \left(\frac{dC_R}{dU_2} + 1 \right) dU_2 \tag{B-11}$$

which comes from

$$L = \theta \, (C_R + U_2) = \theta \, U_2 \left(\frac{C_R}{U_2} + 1 \right) \tag{B-12}$$

combine (B-10), (B-11) and (B-12) eliminating time, (B-11) and (B-12):

$$dL = U_2 \left(\frac{C_R}{U_2} + 1 \right) d\theta + \frac{L[(dC_R/dU_2) + 1] \, dU_2}{U_2[(C_R/U_2) + 1]}$$

and (B-10)

$$\frac{dB}{B} = \alpha_{ci} \frac{U_2}{\delta} \left[\frac{dL}{U_2[(C_R/U_2) + 1]} - \frac{L[(dC_R/dU_2) + 1] \, dU_2}{U_2^2[(C_R/U_2) + 1]^2} \right]$$

$$\frac{dB}{B} = \frac{\alpha_{ci}}{U_2 \, \delta \, [(C_R/U_2) + 1]} \left[U_2 dL - \frac{L[(dC_R/dU_2) + 1] \, dU_2}{(C_R/U_2) + 1} \right] \tag{B-13}$$

From continuity

$$m_f = \pi D \delta \rho_f U_2/2$$

$$\frac{2\,(1 - X)\, m_o}{\pi D \rho_f} = \delta U_2 \tag{B-14}$$

From momentum transfer considerations

$$U_2 = U_v \ (\rho_v/\rho_f)^{1/2} \tag{B-15}$$

combine (B-14), (B-15)and (B-13)

$$\frac{dB}{B} = \frac{\alpha_{ci} \pi D \ \rho_f}{2 \ (1 - X) \ m_o \left[(C_R/U_2) + 1\right]} \left[U_v \ (\rho_v/\rho_f)^{1/2} \ dL - \frac{L\left[(dC_R/dU_2) + 1\right]}{\left[(C_R/U_2) + 1\right]} \ (\rho_v/\rho_f)^{1/2} \ dU_v \right] \tag{B-16}$$

also, from continuity

$$U_v = \frac{X \ m_o}{\frac{\pi D^2}{4} \ \rho_v} \tag{B-17}$$

and

$$dU_v = \frac{4 \ m_o}{\pi \rho_v} \ d\left(\frac{X}{D^2}\right) = \frac{4 \ m_o}{\pi \rho_v} \ \frac{D^2 \ dX - X \ 2 \ DdD}{D^4}$$

$$dU_v = \frac{4 \ m_o}{\pi \rho_v} \left(\frac{dX}{D^2} - 2 \ X \ \frac{dD}{D^3}\right) \tag{B-18}$$

combine (B-18, (B-17) and (B-16)

$$\frac{dB}{B} = \frac{\alpha_{ci} \pi D \ \rho_f \ (\rho_v/\rho_f)^{1/2}}{2(1 - X) \ m_o \left[(C_R/U_2) + 1\right]} \left[\frac{4 \ X \ m_o dL}{\pi D^2 \ \rho_v} - \frac{L\left[(dC_R/dU_2) + 1\right] 4 \ m_o}{\left[(C_R/U_2) + 1\right] \pi \ \rho_v} \left(\frac{dX}{D^2} - 2 \ X \ \frac{dD}{D^3}\right) \right]$$

$$\frac{dB}{B} = \frac{2 \ \alpha_{ci} \ (\rho_f/\rho_v)^{1/2}}{(1 - X) \left[(C_R/U_2) + 1\right]} \left[\frac{X}{D} - \frac{\left[(dC_R/dU_2) + 1\right]}{\left[(C_R/U_2) + 1\right]} \left(\frac{L}{D} \ \frac{dX}{dL} - 2 \ X \ \frac{L}{D^2} \ \frac{dD}{dL}\right) \right] \ dL$$

integrating from neutral stability to transition

$$\ln \frac{B^*}{B_n} = \frac{2}{(C_R/U_2)+1} (\rho_f/\rho_v)^{1/2} \int_{L_n}^{L^*} \frac{\alpha_{ci}}{1 - X} \left[\frac{X}{D} - \frac{(dC_R/dU_2)+1}{(C_R/U_2)+1} \left(\frac{L}{D}\frac{dX}{dL} - 2 X \frac{L}{D^2} \frac{dD}{dL} \right) \right] dL \qquad \text{(B-19)}$$

Assume:

$D = D_o$ = constant

$1 - X = L/L_c$; $dX = -dL/L_c$

$dC_r/dU_2 << 1$

α_{ci} = constant

(B-19) becomes:

$$\ln \frac{B^*}{B_n} = \frac{2 \alpha_{ci}}{(C_R/U_2)+1} \frac{\rho_f}{\rho_v}^{1/2} \int_{L_n}^{L^*} \frac{L_c}{L} \left[\frac{(1 - L/L_c)}{D_o} - \frac{1}{(C_R/U_2 + 1)} \frac{L}{D_o} \left(- \frac{1}{L_c} \right) \right] dL$$

$$\ln \frac{B^*}{B_n} = \frac{2 \alpha_{ci}}{(C_R/U_2)+1} \left(\frac{\rho_f}{\rho_v}\right)^{1/2} \int_{L_n}^{L^*} \left[\frac{L_c}{L} - 1 + \frac{1}{(C_R/U_2)+1} \right] \frac{dL}{D_o}$$

For most cases

$C_R/U_2 << 1$

then,

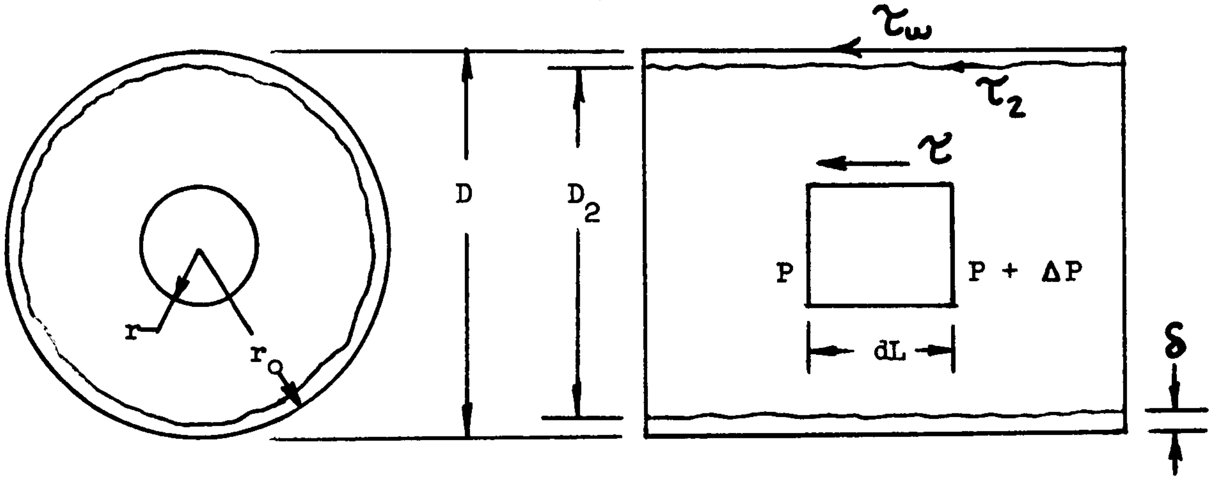
$$\ln \frac{B^*}{B_n} = 2 \alpha_{ci} (\rho_f/\rho_v)^{1/2} \int_{L_n}^{L^*} \frac{L_c}{D_o} \frac{dL}{L}$$

$$\ln \frac{L^*}{Ln} = \left[\ln \frac{B^*}{B}\right]\left[2\alpha\, c_i\left(\frac{\rho_f}{\rho_v}\right)^{1/2}\right]^{-1} \qquad \text{(B-20)}$$

APPENDIX B-3

TWO-PHASE PRESSURE DROP

It is convenient to consider the frictional and momentum effects on the pressure changes during condensing separately. The following analysis applies to frictional portion of the pressure drop:



The frictional pressure drop is related to the shear stress by a force balance, namely,

$$\pi r^2 P = \pi r^2 (P + dP) + \tau 2 \pi r \, dL$$

$$dP/dL = - \frac{2\tau}{r}$$

The pressure is assumed not to vary in the radial direction, therefore,

$$(dP/dL)_{TP} = - \frac{2\tau_w}{r_o}$$

and at the liquid vapor interface,

$$dP/dL = - \frac{2\tau_2}{r_2} = - \frac{2\tau_2}{r_o(1 - \frac{\delta}{r_o})}$$

Note that for a thin liquid film

$$\frac{\delta}{r_o} <<< 1$$

$$\tau_2 = \tau_w$$

Defining a frictional pressure drop assuming only vapor to flow in a tube, we have

$$\frac{dP_v}{dL} = \frac{-2\tau_v}{r_o}$$

Introducing the Lockhart-Martinelli two-phase frictional pressure drop modulus,

$$\frac{(dP/dL)_{TP}}{(dP_v/dL)} \equiv \Phi_v^2 = \frac{\tau_2}{\tau_v[1-(\delta/r_o)]}$$

note that

$$\frac{D_2}{D} = \frac{D-2\delta}{D} = 1 - \frac{\delta}{r_o}$$

therefore,

$$\Phi_v^2 = \frac{\tau_2}{\tau_v}\left(1 - \frac{2\delta}{D}\right)^{-1} = \frac{\tau_2}{\tau_v}\frac{D}{D_2} \qquad \text{(B-21)}$$

Since τ_v is computable by means of single phase fluid mechanics, it can be seen that the salient problem in two-phase fluid mechanics is the determination of τ_2 and δ.

For a thin laminar liquid film with a linear velocity profile, the following hold true (pressure gradient effects neglected in a thin film):

$$\tau_w = \tau_2 = \frac{\mu_f}{g_c}\frac{U_2}{\delta} \qquad \text{(B-22)}$$

and if all of the liquid flow is contained in the film, then

$$m_f = \frac{U_2}{2}\rho_f\,\pi\,D\,\delta \qquad \text{(B-23)}$$

eliminating U_2 from (B-22) and (B-23)

$$\tau_2 = \frac{\mu_f\,2\,m_f}{g_c\,\delta^2\,\rho_f\,\pi\,D}$$

$$\left(\frac{\delta}{D}\right)^2 = \frac{2\,m_f\,\mu_f}{\tau_2\,g_c\,\rho_f\,\pi\,D^3} \qquad \text{(B-24)}$$

$$1/4\left(1 - \frac{D_2}{D}\right)^2 = \frac{2\,m_f\,\mu_f}{\tau_2\,g_c\,\rho_f\,\pi\,D^3} \qquad \text{(B-25)}$$

Returning to (B-21) and expressing the shear stress in terms of friction factors, we have

$$\tau_v \equiv \frac{f_v}{8} \quad \frac{\rho_v \; U_v^2}{g_c}$$

$$\tau_2 \equiv \frac{f_2}{8} \quad \frac{\rho_v \; U_{v_2}^2}{g_c}$$

Therefore,

$$\frac{\tau_2}{\tau_v} \doteq \frac{f_2}{f_v} \left(\frac{U_{v_2}}{U_v} \right)^2 \tag{B-26}$$

<u>Laminar Film - Laminar Vapor Core</u>

For <u>laminar</u> flow of the vapor and assuming a smooth liquid vapor interface:

$$\frac{f_2}{f_v} = \frac{\dfrac{64}{4 \; m_v / \pi \, D_2 \, \mu_v}}{\dfrac{64}{4 \; m_v / \pi \, D \, \mu_v}} = \frac{D_2}{D} \tag{B-27}$$

also, from continuity,

$$\frac{\pi D_2}{4} \; \rho_v \, U_{v_2} = \frac{\pi \, D}{4} \; \rho_v \, U_v$$

$$\frac{U_{v_2}}{U_v} = \left(\frac{D}{D_2} \right)^2 \tag{B-28}$$

combining (B-26), (B-27) and (B-28)

$$\frac{\tau_2}{\tau_v} = \left(\frac{D_2}{D} \right) \left(\frac{D}{D_2} \right)^4 \tag{B-29}$$

combining (B-29) with (B-21)

$$\Phi_v^2 = \left(\frac{D_2}{D} \right) \left(\frac{D}{D_2} \right)^4 \left(\frac{D}{D_2} \right) = \left(\frac{D}{D_2} \right)^{4.0} \tag{B-30}$$

The ratio D/D_2 in (B-30) can be computed by means of (B-25) as follows:

$$\tau_2 \equiv \frac{f_2}{8} \frac{\rho_v U_{v_2}^{\,2}}{g_c} = \frac{64 \rho_v U_v^2}{8\left(\frac{4 m_v}{\pi D \mu_v}\right) \frac{D}{D_2} g_c} \left(\frac{D}{D_2}\right)^4$$

$$\tau_2 = \frac{64}{8 Re_v} \frac{\rho_v U_v^2}{g_s} \left(\frac{D}{D_2}\right)^{15/4} \qquad \text{(B-31)}$$

where Re_v is the superficial vapor Reynolds Number computed as if vapor alone were flowing. Substitute (B-31) into (B-25) noting that

$$f_v = \frac{64}{Re_v}$$

$$\frac{1}{4}\left(1 - \frac{D_2}{D}\right)^2 = \frac{2 m_f \mu_f}{\frac{f_v}{8} \frac{\rho_v U_v}{g_s} \left(\frac{D}{D_2}\right)^3 g_s \rho_f \pi D^3}$$

$$\left(\frac{D}{D_2}\right)^3 \left(1 - \frac{D_2}{D}\right)^2 = \frac{64 m_f \mu_f}{f_v \rho_v U_v^2 \rho_f \pi D^3}$$

Substitute:

$$\rho_v U_v = \frac{4 m_v}{\pi D^2}$$

$$\left(\frac{D}{D_2}\right)^3 \left(1 - \frac{D_2}{D}\right)^2 = \frac{64 m_f \mu_f}{f_v \frac{4 m_v}{\pi D^2} U_v \rho_f \pi D^3}$$

$$\left(\frac{D}{D_2}\right)^3 \left(1 - \frac{D_2}{D}\right)^2 = \frac{16}{f_v Re_v} \left(\frac{m_f}{m_v}\right)\left(\frac{\mu_f}{\mu_v}\right)\left(\frac{\rho_v}{\rho_f}\right) \qquad \text{(B-32)}$$

$$\left(\frac{D}{D_2}\right)^3 - 2\left(\frac{D}{D_2}\right)^2 + \frac{D}{D_2} - \left(\frac{16}{f_v Re_v}\right)\left(\frac{m_f}{m_v}\right)\left(\frac{\mu_f}{\mu_v}\right)\left(\frac{\rho_v}{\rho_f}\right) = 0$$

(B-33)

A simplified approximate solution for D/D_2 can be derived starting with equation (B-32). For simplicity, let the right hand side, equal to a constant K

$$\left(\frac{D}{D_2}\right)^3 \left(1 - \frac{D_2}{D}\right)^2 = K$$

$$\left(\frac{D}{D_2}\right)^{1.5} \left(1 - \frac{D_2}{D}\right) = K^{.5}$$

$$\left(\frac{D}{D_2}\right)\left(1 - \frac{D_2}{D}\right) = K^{.5} \left(\frac{D_2}{D}\right)^{.5}$$

assume:

$$\left(\frac{D_2}{D}\right)^{.5} \approx 1.0$$

then:

$$\left(\frac{D}{D_2}\right) = 1 + \left[\left(\frac{16}{f_v Re_v}\right)\left(\frac{m_f}{m_v}\right)\left(\frac{\mu_f}{\mu_v}\right)\left(\frac{\rho_v}{\rho_f}\right)\right]^{.5} \qquad \text{(B-34)}$$

Investigating percent error involved in using (B-34) instead of true solution of (B-33).

Let $(D/D_2) = 1.2$ (this assumes approximately 30% of cross-sectional area is taken up by liquid). This can well be considered the upper limit for (D/D_2). Using equation (B-30)

$$\Phi_v^2 = (1.2)^4 = 2.074 \qquad \text{(exact solution)}$$

From (B-33)

$$\left(\frac{16}{f_v Re_v}\right)\left(\frac{m_f}{m_v}\right)\left(\frac{\mu_f}{\mu_v}\right)\left(\frac{\rho_v}{\rho_f}\right) = K$$

$$= (1.2)^3 - 2\,(1.2)^2 + 1.2$$

$$= .048$$

Then from (B-34)

$$\frac{D}{D_2} = 1 + (.048)^{.5} = 1.219$$

$$\Phi_v^2 = (1.219)^4 = 2.208$$

$$\% \text{ error} = \frac{(2.208 - 2.074)\,100}{2.074}$$

$$= 6.47\%$$

For a more typical value of D/D_2, say of 1.05:

$$\% \text{ error} = \frac{(1.0513)^4 - (1.05)^4}{1.05^4}$$

$$= \frac{.006027}{1.2155}$$

$$= .495\%$$

Based on these findings, the simpler equation (B-34) rather than the solution of (B-33) can be used with negligible error.

Laminar Film - Turbulent Vapor Core

For turbulent flow of the vapor phase and assuming a smooth liquid vapor interface,

$$\frac{f_2}{f_v} = \frac{\dfrac{.316}{(4\, m_v/\pi D_2 \mu_v)^{1/4}}}{\dfrac{.316}{(4\, m_v/\pi D \mu_v)^{1/4}}} = \left(\frac{D_2}{D}\right)^{1/4}$$

Also, from continuity,

$$\frac{\pi D_2^{\,2}}{4} \rho_v U_{v2} = \frac{\pi D}{4} \rho_v U_v$$

$$\frac{U_{v2}}{U_v} = \left(\frac{D}{D_2}\right)^2$$

combining

$$\frac{\tau_2}{\tau_v} = \left(\frac{D_2}{D}\right)^{1/4} \left(\frac{D}{D_2}\right)^4 \qquad \text{(B-35)}$$

combining (B-35) with (B-21) results in

$$\Phi_v^2 = \left(\frac{D_2}{D}\right)^{1/4} \left(\frac{D}{D_2}\right)^4 \left(\frac{D}{D_2}\right) = \left(\frac{D}{D_2}\right)^{19/4} = \left(\frac{D}{D_2}\right)^{4.75} \qquad \text{(B-36)}$$

The ratio D/D_2 in (B-36) can be computed by means of (B-25) as follows:

$$\tau_2 \equiv \frac{f_2}{8} \frac{\rho_v U_{v2}^2}{g_s} = \frac{.316}{8\left(\frac{4m_v}{\pi D \rho_v}\right)^{1/4}\left(\frac{D}{D_2}\right)^{1/4}} \frac{\rho_v U_v^2}{g_s} \left(\frac{D}{D_2}\right)^4$$

$$\tau_2 = \frac{.316}{8 \, Re_v^{1/4}} \frac{\rho_v U_v^2}{g_s} \left(\frac{D}{D_2}\right)^{15/4} \qquad \text{(B-37)}$$

where Re_v is the superficial vapor Reynolds Number computed as if vapor alone were flowing. Substitute (B-37) into (B-25) noting that

$$f_v = \frac{.316}{Re_v^{1/4}}$$

$$1/4 \left(1 - \frac{D_2}{D}\right)^2 = \frac{2 \, m_f \, \mu_f}{\frac{f_v}{8} \frac{\rho_v U_v}{g_s} \left(\frac{D}{D_2}\right)^{15/4} g_s \, \rho_f \, \pi D^3}$$

$$\left(\frac{D}{D_2}\right)^{15/4} \left(1 - \frac{D_2}{D}\right)^2 = \frac{64 \, m_f \, \mu_f}{f_v \, \rho_v \, U_v^2 \rho_f \, \pi D^3}$$

Substitute:

$$\rho_v U_v = \frac{4 \, m_v}{\pi D^2}$$

$$\left(\frac{D}{D_2}\right)^{15/4} \left(1 - \frac{D_2}{D}\right)^2 = \frac{64 \, m_f \, \mu_f}{f_v \frac{4 \, m_v}{\pi D^2} U_v \, \rho_f \, \pi D^3}$$

$$\left(\frac{D}{D_2}\right)^{15/4} \left(1 - \frac{D_2}{D}\right)^2 = \frac{16}{f_v \, Re_v} \left(\frac{m_f}{m_v}\right)\left(\frac{\mu_f}{\mu_v}\right)\left(\frac{\rho_v}{\rho_f}\right) \qquad \text{(B-38)}$$

$$\left(\frac{D}{D_2}\right)^{1.875} - \left(\frac{D}{D_2}\right)^{.875} - \left[\left(\frac{16}{f_v \, Re_v}\right)\left(\frac{m_f}{m_v}\right)\left(\frac{\mu_f}{\mu_v}\right)\left(\frac{\rho_v}{\rho_f}\right)\right]^{.5} = 0 \qquad \text{(B-39)}$$

Again, a simplified solution for D/D_2 can be derived from (B-38)

$$\left(\frac{D}{D_2}\right)^{15/4} \left(1 - \frac{D_2}{D}\right)^2 = K$$

$$\left(\frac{D}{D_2}\right)^{15/8} \left(1 - \frac{D_2}{D}\right) = K^{.5}$$

$$\left(\frac{D}{D_2}\right)^2 \left(1 - \frac{D_2}{D}\right) = K^{.5} \left(\frac{D}{D_2}\right)^{.125}$$

Assume

$$\left(\frac{D}{D_2}\right)^{.125} \approx 1$$

then:

$$\left(\frac{D}{D_2}\right)^2 - \frac{D}{D_2} - K^{.5} = 0$$

$$\frac{D}{D_2} = .5 + \left\{ .25 \left[\left(\frac{16}{f_v Re_v}\right) \left(\frac{m_f}{m_v}\right) \left(\frac{\mu_f}{\mu_v}\right) \left(\frac{\rho_v}{\rho_f}\right)\right]^{.5} \right\}^{.5} \qquad \text{(B-40)}$$

Again, investigating maximum error with $(D/D_2) = 1.2$ using (B-36),

$$\Phi_v^2 = (1.2)^{4.75} = 2.37$$

from (B-39)

$$\left[\left(\frac{16}{f_v\ Re_v}\right) \left(\frac{m_f}{m_v}\right)\left(\frac{\mu_f}{\mu_v}\right) \left(\frac{\rho_v}{\rho_f}\right)\right]^{.5} = (1.2)^{1.875} - (1.2)^{.875}$$

$$= 1.408 - 1.173$$

$$= .235$$

Using equation (B-40)

$$\frac{D}{D_2} = .5 + (.25 + .235)^{.5}$$

$$= 1.197$$

$$\% \text{ error} = \frac{(1.2)^{4.75} - (1.197)^{4.75}}{(1.2)^{4.75}}$$

$$= .835\%$$

Again, the simpler equation (B-40), rather than the solution for D/D_2 from equation (B-39) can be used.

Fog or Homogeneous Flow

For fog or homogenous flow (also see reference 24 for detailed analysis) start with (B-21) as follows:

$$\Phi_v^2 = \frac{D}{D_2}\frac{\tau_2}{\tau_v} = \frac{D}{D_2}\frac{(f_m/8)\,\rho_m\,U_m^2}{(f_v/8)\,\rho_v\,U_v^2} = \frac{D}{D_2}$$

$$\frac{f_m}{f_v}\frac{\rho_m}{\rho_v}\left(\frac{U_m}{U_v}\right)^2$$

Note: Subscript m denotes mixture.

From reference 24

$$\frac{f_m}{f_v} = \left[\frac{D_2}{D} \quad X_E\right]^{1/4} \qquad \text{turbulent flow}$$

$$\frac{\rho_m}{\rho_v} = \frac{1}{X_E} \qquad \text{if the volume of the liquid phase is small contrasted to the vapor phase.}$$

From continuity

$$U_m = U_v\left(\frac{D}{D_2}\right)^2$$

we now obtain

$$\Phi_v^2 = \frac{D}{D_2}\left(\frac{D_2}{D}\,X_E\right)^{1/4}\frac{1}{X_E}\left(\frac{D}{D_2}\right)^4 = \left(\frac{D}{D_2}\right)^{4.75}\frac{1}{X_E^{\;3/4}}$$

For the limiting case when no liquid appears on the wall ($X_E = X$ and $D/D_2 = 1$), we obtain a simple equation for fog flow, namely,

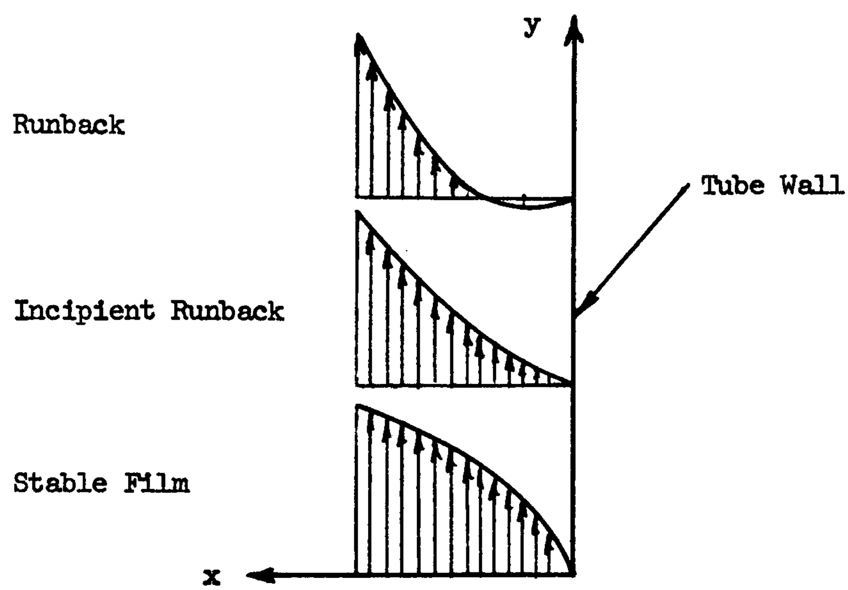
$$\Phi_v^2 \text{ (fog flow)} = 1/X^{3/4} \qquad \text{(B-41)}$$

Experimental corroboration of equation (B-41) is shown in Figure B-5 (from reference 29). In this curve, the $\Phi_v^2 X^{3/4}$ term approaches 1.0 as the Weber number, $D \rho_v U_v^2 / 2 g_c \sigma$, increases. This high Weber number indicates a negligible effect of wall-bound film (or drops) and the two-phase frictional effect is produced by the entrained liquid, only. Although this data was obtained with mercury in 1-g, the correlation was followed when artificial wetting (or film condensation) was induced. Furthermore, references 30 and 31 show experimental agreement with the correlation for tapered tubes and zero g.

APPENDIX B-4

SINGLE TUBE INSTABILITY

In examining single tube instability, the first step is to analyze the conditions at the incipient runback point* to differentiate between negligible and predominant factors. Reference 33 gives the following film velocity profiles for conditions of a stable film, incipient runback, and runback.



At the incipient runback point it can be seen that the velocity gradient at the wall is zero and the wall shear stress is therefore zero. It will also be assumed that there is no velocity in the X-direction and that the change in velocity in the Y-direction is negligible.

This latter assumption is pessimistic since it neglects the effect of the liquid momentum gain due to the effect of decreasing liquid velocity as the incipient runback point is reached. The last assumption is that the (vapor) pressure gradient is negligible which is also pessimistic since the pressure gradient would tend to support the film. Consider an incremental area within the liquid film:

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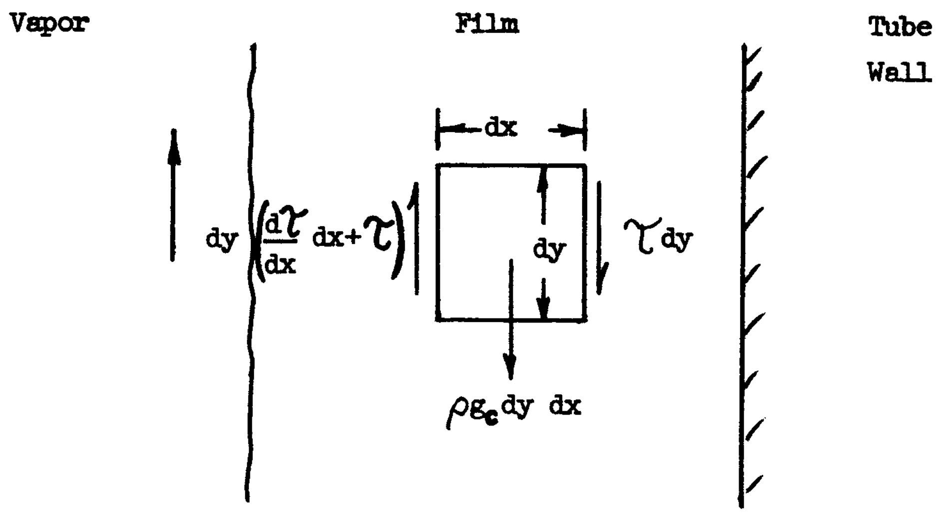
* That point at which the film velocity becomes zero and its thickness will grow until the tube is bridged.



Balancing the forces yields:

$$\left(\frac{d\tau}{dx}\,dx + \tau\right) dy = n\,\rho_l\,g_c\,dy\,dx + \tau dy \tag{B-42}$$

but

$$\tau = \mu_l\,\frac{dU_y}{dx}$$

and

$$\frac{d\tau}{dx} = \mu_l\,\frac{d^2U_y}{dx^2}$$

which on substitution into equation (B-42) yields:

$$\frac{d^2U_y}{dx^2} = \frac{U\rho_l g_c}{\mu_l}$$

integrating

$$\frac{dU_y}{dx} = \frac{n\rho_l g_c x}{\mu_l} + C_1$$

but since the limit for stability is $dU_y/dx = 0$ at $x = 0$ and $C_1 = 0$.

Therefore,

$$U_y = \frac{n x^2 \rho_l g_c}{2\mu_l} + C_2$$

but

$$C_2 = 0 \text{ at } x = 0,\ U_y = 0$$

and finally,

$$U_y = \frac{nX^2 \rho_\ell g_c}{2 \mu_\ell}$$

and at

$$X = \delta \ , \ U_y = U_i \tag{B-43}$$

$$\frac{n \rho_\ell g_c}{\mu_\ell} \quad \frac{\delta^2}{2} = U_i \qquad \text{where } \delta = \text{film thickness}$$

since the velocity profile is parabolic the average velocity is 1/3 of the interfacial velocity (U_i) and from continuity:

$$\frac{U_i}{3} \rho_\ell \delta \pi D = m_\ell \tag{B-44}$$

Substituting equation (B-43) into equation (B-44) yields:

$$\frac{n \rho_\ell^2 g_c \delta^3 \pi D}{6 \mu_\ell} = m_\ell$$

but

$$\tau_i = n \delta \rho_\ell$$

and finally,

$$\tau_i = n \left(\frac{6 \mu_\ell m_\ell \rho_\ell}{\pi D g_c} \right)^{1/3} \tag{B-45}$$

which gives the expression for the interfacial shear at the runback point. However, the net interfacial shear is made up of two components; the frictional shear, τ_f, and the momentum shear, τ_{mom}, where:

$$\tau_i = \tau_f + \tau_{mom}$$

$$\tau_f = \frac{f}{4} \rho_v \frac{U_v^2}{2 g_c} \tag{B-46}$$

$$\tau_{mom} = \frac{\Delta m_v U_v}{\pi D \Delta L g_c} \tag{B-47}$$

where Δm_v = vapor condensed.

Equating (B-45), (B-46) and (B-47) yields:

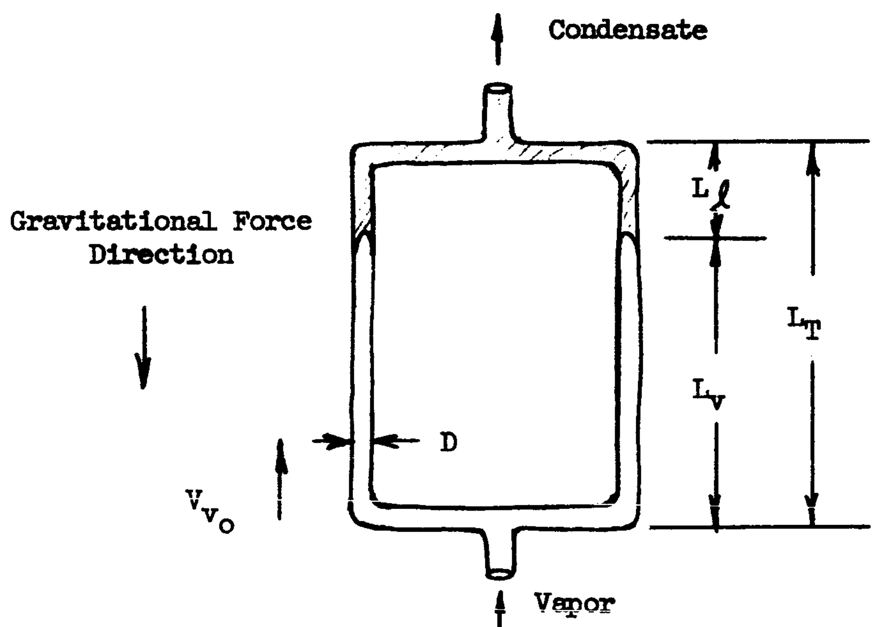
$$n \left(\frac{6 \mu_\ell m_\ell \rho_\ell}{\pi D g_c} \right)^{1/3} = \frac{f}{4} \rho_v \frac{U_v^2}{2 g_c} + \frac{\Delta m_v U_v}{\pi D \Delta L g_c}$$

APPENDIX B-5

MULTIPLE TUBE INSTABILITY

The following is a discussion of the multiple tube mode of instability.

As an example, assume the following condenser:



$$\Delta P_s = \Phi^2_{v\,int} \; f_{int} \frac{L_v}{D} \frac{\rho_v U_{v_o}^2}{2\, g_c} - \frac{\rho_v U_v^2}{g_c} + L_\ell \quad \rho_\ell \, n$$

also:

$$q\, L_v = m_{v_o} h_{fg} = \frac{\pi D^2}{4} G_o h_{fg}$$

where q = heat rejection per unit length and time.

Combining equations results in:

$$\Delta P_s = \Phi^2_{v_{int}} \; f_{int} \frac{\pi D\, G_o^3 h_{fg}}{8q\, g_c\, \rho_v} - \frac{G_o^2}{\rho_v\, g_c} +$$

$$\left(L_T - \frac{\pi D^2}{4} \frac{G_o h_{fg}}{q} \right) \rho_\ell \, n$$

differentiating:

$$\frac{d\,\Delta P_s}{d\,G_o} = \Phi^2_{v_{int}}\; f_{int}\; \frac{\pi D\, h_{fg}\; 3\, G_o^2}{8\, q\, g_c\, \rho_v} - \frac{G_o^2}{\rho_v g_c} + \left(- \frac{\pi D^2 h_{fg}\, \rho_\ell\, n}{4\, q} \right)$$

substituting:

$$\frac{\pi D^2}{4}\quad \frac{h_{fg}}{q} = \frac{L_v}{G_o} \tag{B-22}$$

$$\frac{d\,(\Delta P_s)}{d\,G_o} = \left(\frac{\Phi_{int}\; f_{int}\; L_v}{D} - \frac{4}{3} - \frac{2\, L_v\, \rho_\ell\, n\, g_c\, \rho_v}{3\, G_o^2} \right) \frac{3\, G_o}{2\, g_c\, \rho_v}$$

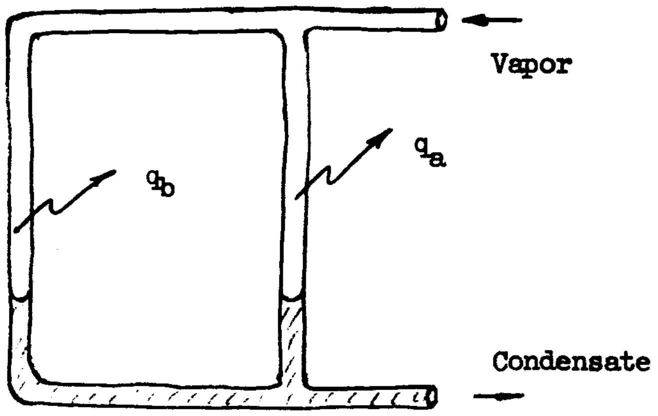
From reference 32, a necessary and sufficient condition for stability is that $d\,(\Delta P_s)/dG_o$ is positive. This requires that:

$$\Delta P_f > \frac{2}{3}\; \frac{G_o^2}{\rho_v g_c} + \frac{L_v\, \rho_\ell\, n}{3}$$

APPENDIX B-6

PRIMARY/SECONDARY DESIGN ANALYSIS

Consider the two-tube condenser below operating in zero or micro-gravity.



If now, an unbalance is imposed on the system, say, the heat rejection capability per unit length of tube No. 1 becomes greater than tube No. 2,

$$q_a > q_b$$

and

$$m_{v_a} > m_{v_b} \qquad \text{(vapor mass flow rates)}$$

This means that the pressure drops are unequal.

$$\Delta P_a > \Delta P_b$$

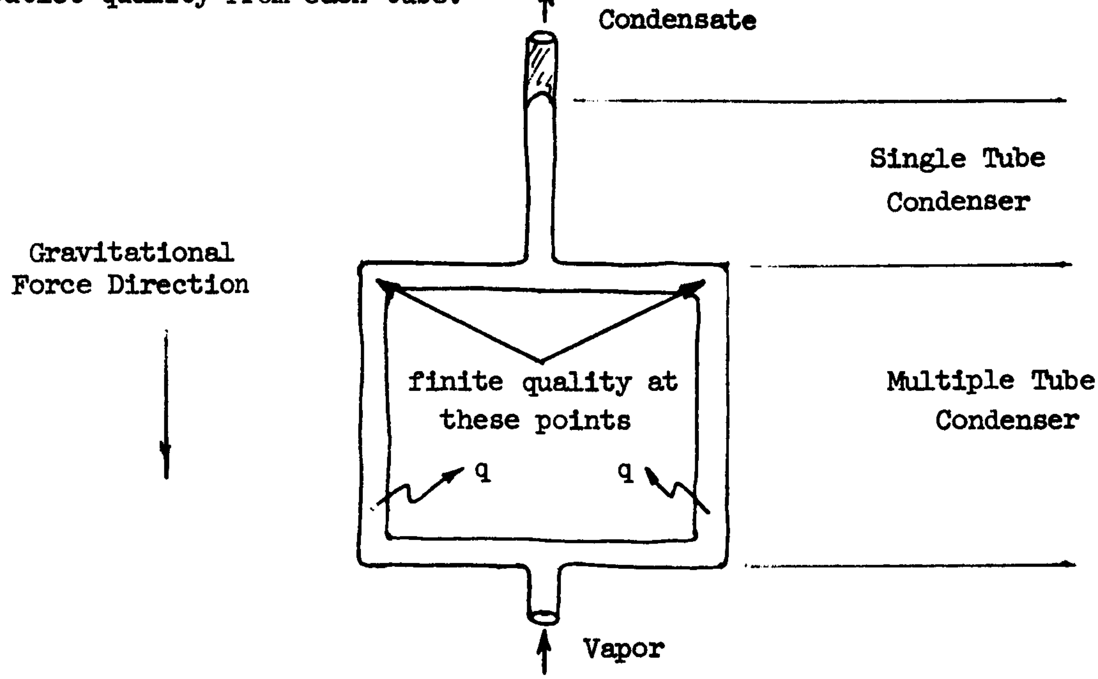
However, since the tube inlet pressures are equal (assuming negligible header pressure drop), the interface pressures are unequal, which is not a stable condition. Therefore, the unbalance is compensated for by adjustment of the interface location until

$$\Delta P_a = \Delta P_b \text{ at which } l_{c_a} > l_{c_b} \text{ and } m_{v_a} > m_{v_b}$$

where l_c are the respective condensing lengths.

However, for a condenser designed for operation against a substantial "g" field, this readjustment of liquid legs may produce a catastrophic unbalance as a result

of the static pressure effects of the varying liquid leg lengths. An alternative would be to remove the interface from the parallel tube array to a point downstream in a single tube. With this arrangement shown in the sketch below, the unbalances which were compensated for with shifting liquid legs in a multiple interface condenser are, in this case, compensated for by a variation in the outlet quality from each tube.



Obviously, the design exit quality of the parallel tubes must be sufficiently large to compensate for the unbalances without allowing the vapor velocity to drop below that value required for film transport. Nor does one want to have too high an outlet quality because of the weight penalty involved. The minimum exit quality to meet the above requirements can be approximated assuming reasonable geometric and thermal unbalances.

Assuming a tapered condenser tube with a constant vapor velocity and neglecting the small momentum recovery which results, the following analysis investigates the necessary outlet quality (based on 100% inlet quality) for stability in the parallel tube portion of the condenser.

Friction:

$$dP_s = \Phi_v^2 \; f_v \; \frac{(GX)^2}{\rho_v \, 2g_c} \; \frac{dL}{D} \qquad \text{(B-48)}$$

Thermal balance:

$$dL = - \frac{Gh_{fg}}{q} \; \frac{\pi D^2}{4} \; dX \qquad \text{(B-49)}$$

Combining equations (B-48) and (B-49) gives

$$dP = \left(\Phi_v^2 \; f_v \quad \frac{(GX)^2}{\rho_v \, 2 \, g_c}\right)\left(- \; \frac{Gh_{fg}\,\pi\, D^2}{4 \, D \, q}\right) dX$$

$$dP = C_1 \; \frac{G^3 \, X^2 \, D}{q} \; dX \qquad \text{(B-50)}$$

where

$$C_1 = \frac{\Phi_v^2 \; f_v \, \pi \; h_{fg}}{8 \; \rho_v \, g_s} \qquad \text{(assumed constant)}$$

where q = heat rejection per unit length.

The assumption that Φ_v^2 and f_v are constant will not affect the result greatly since, in the following analysis, two condensing tubes will be compared and these values will change very little from tube to tube over the quality ranges to be examined. The use of an average D rather than an integrated one should also have little effect since the pressure drop of one tube is to be compared to another rather than the absolute value obtained.

Integrating equation (B-50):

$$\int_{P_o}^{P_e} dP = C_1 \left(\frac{G^3 D}{q}\right) \int_{X_0=1}^{X_e} X^2 dX$$

$$P_e - P_o = C_1 \left(\frac{G^3 D}{q}\right)\left[\frac{X_e^{\,3}}{3} - \frac{1}{3}\right]$$

$$P_o - P_e = C_1 \left(\frac{G^3 D}{q}\right)\left[\frac{1 - X_e^{\,3}}{3}\right] \qquad \text{(B-51)}$$

where

P_o = inlet pressure

P_e = exit pressure

Integrating and solving for G:

$$\int_0^L dL = - \; \frac{Gh_{fg}\,\pi\, D^2}{4 \, q} \int_{X_0=1}^{X_e} dX$$

$$L = - \frac{G h_{fg} \pi D^2}{4 q} (X_e - 1)$$

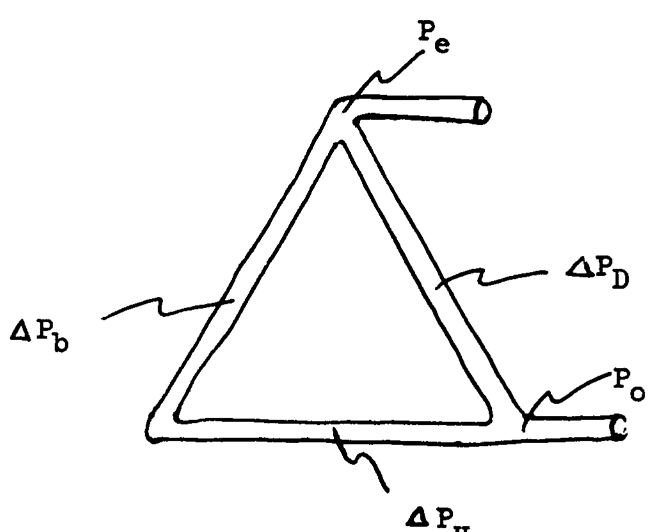
$$G = \frac{4 L q}{\pi D^2 h_{fg} \quad (1 - X_e)} \qquad \text{(B-52)}$$

Combining equations (B-51) and (B-52)

$$P_1 - P_e = C_2 \left(\frac{q^2}{D^5} \right) \frac{(1 - X_e{}^3)}{(1 - X_e)^3} \qquad \text{(B-53)}$$

$$C_2 = C_1 \left(\frac{1}{3} \right) \left(\frac{4 L}{\pi h_{fg}} \right)^3$$

Equation (B-53) provides an expression for tube exit quality as a function of tube geometric and thermal characteristics. This can now be applied to two parallel operating tubes as shown in the following sketch.



It can be seen that

$$\Delta P_b + \Delta P_H = \Delta P_D$$

where

ΔP_H = the header friction loss.

Assume, for discussion purposes,

$$\Delta P_H = .02 \text{ psi}$$

$$\Delta P_D = 0.5 \text{ psi}$$

which means:

$$\Delta P_b = 0.48 \text{ psi}$$

Allow tube D to operate at design conditions and tube b to deviate from design to the extent that

$$\begin{aligned} q_b &\equiv \epsilon_q q_D \\ D_b &\equiv D_D/\epsilon_G \\ X_{eb} &\equiv \alpha X_{eD} \end{aligned} \qquad \text{(B-54)}$$

where

subscript D = design conditions
subscript b = actual conditions in the "worst" tube

Then, using equations (B-53) and (B-54) and cancelling

$$\frac{\Delta P_D - \Delta P_H}{P_D} = \frac{0.48}{0.50} = \frac{\left[1 - (\alpha X_{eD})^3\right]}{\left[1 - (\alpha X_{eD})\right]^3} \frac{\left[1 - X_{eD}\right]^3}{\left[1 - (X_{eD})^3\right]} \epsilon_q^{\,2} \epsilon_G^{\,5} \qquad \text{(B-55)}$$

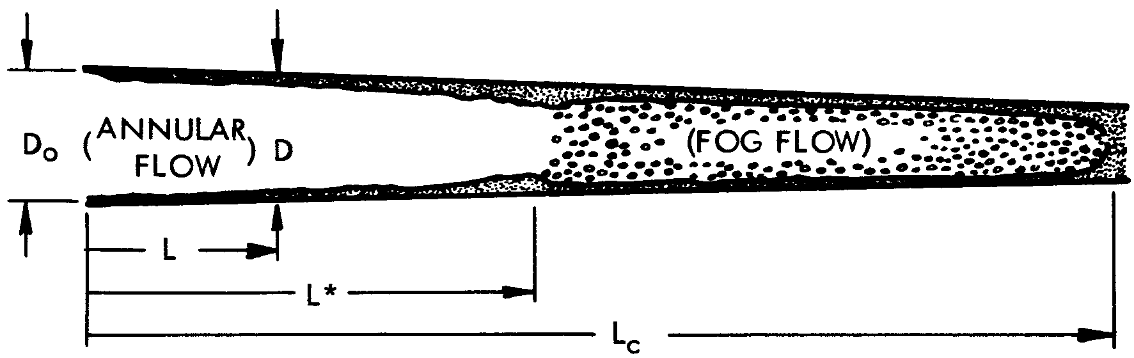
Equation (B-55) then expresses the effect of thermal, geometric, and fluid dynamic unbalances between tubes on the design outlet quality necessary to maintain the vapor velocity greater or equal to α times the design exit vapor velocity. Equation (B-52), however, still has two unknowns, α and X_{eD} or design outlet quality, even after ϵ_D and ϵ_q are determined. However, these two numbers are related since

$$\frac{X_{eb}}{X_{eD}} = \frac{V_{eb}}{V_{eD}} = \alpha$$

Figure B-6 then expresses equation (B-54) for a thermal unbalance of 5% and a diametral unbalance of 1%. For instance, with an outlet quality from the parallel tubes of 15% and a film transport requirement of 40 ft/sec, the condenser would have to be designed with a vapor velocity of 65 ft/sec to insure that the minimum vapor velocity of 40 ft/sec would not be violated in an unbalanced tube.

In this design approach, obviously, the single tube condenser would have to reject the remaining latent heat from the vapor. This concept combines the lightness of a parallel tube condenser-radiator with the stability of a single tube radiator.

PICTORIAL REPRESENTATION OF FILM INSTABILITY



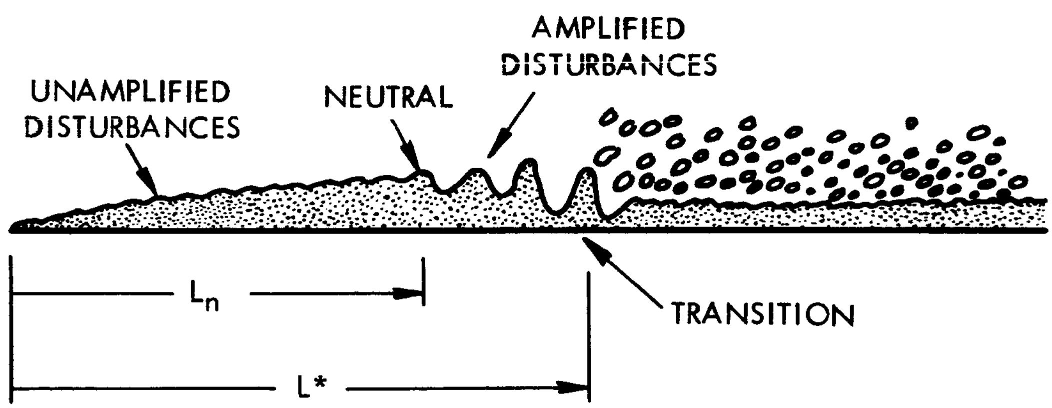


Figure B-1

VARIATION IN R_f AND W_f IN A CONDENSER TUBE

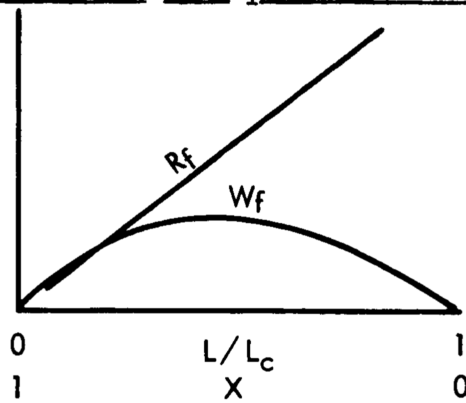


Figure B-2

KELVIN-HELMHOLTZ NEUTRAL STABILITY LOCATION AS A FUNCTION OF INLET VAPOR WEBER NUMBER (WATER IN A CONSTANT DIAMETER TUBE)

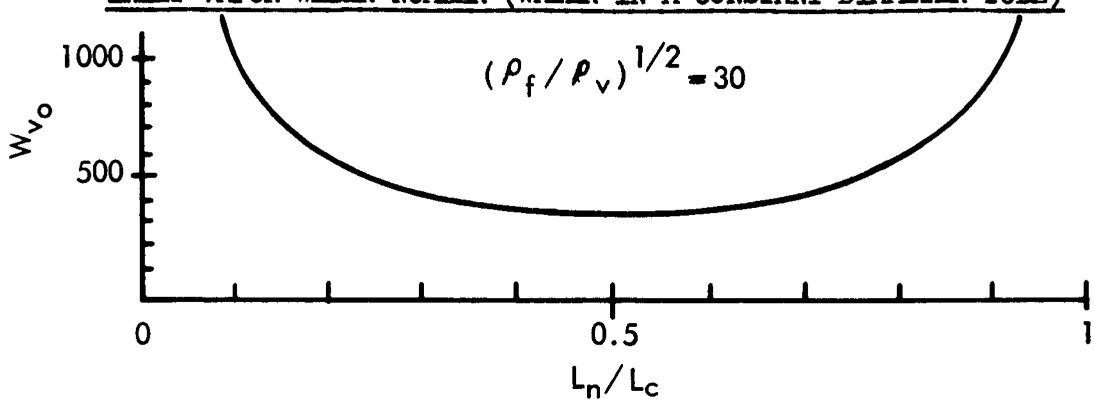


Figure B-3

SCHLICHTING-TOLLMIEN NEUTRAL STABILITY LOCATION AS A FUNCTION OF INLET VAPOR REYNOLDS NUMBER (WATER IN A CONSTANT DIAMETER TUBE)

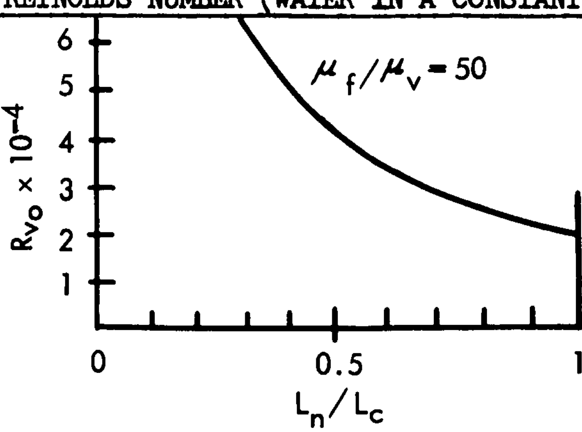


Figure B-4

COMPARISON OF WETTING MERCURY
CONDENSING PRESSURE DROP WITH FOG-FLOW PREDICTION

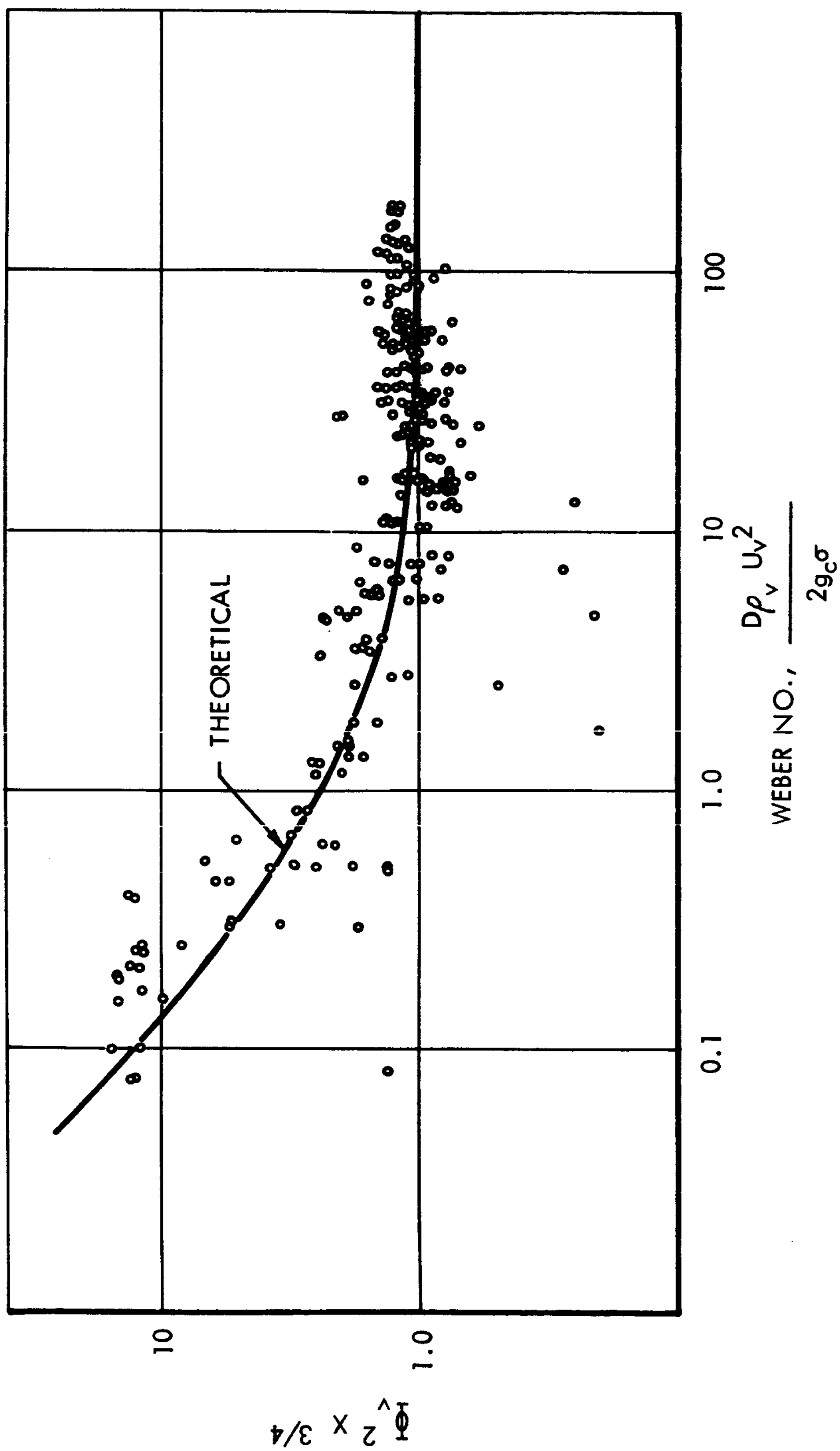


Figure B-5

PARALLEL TUBE STABILITY REQUIREMENTS

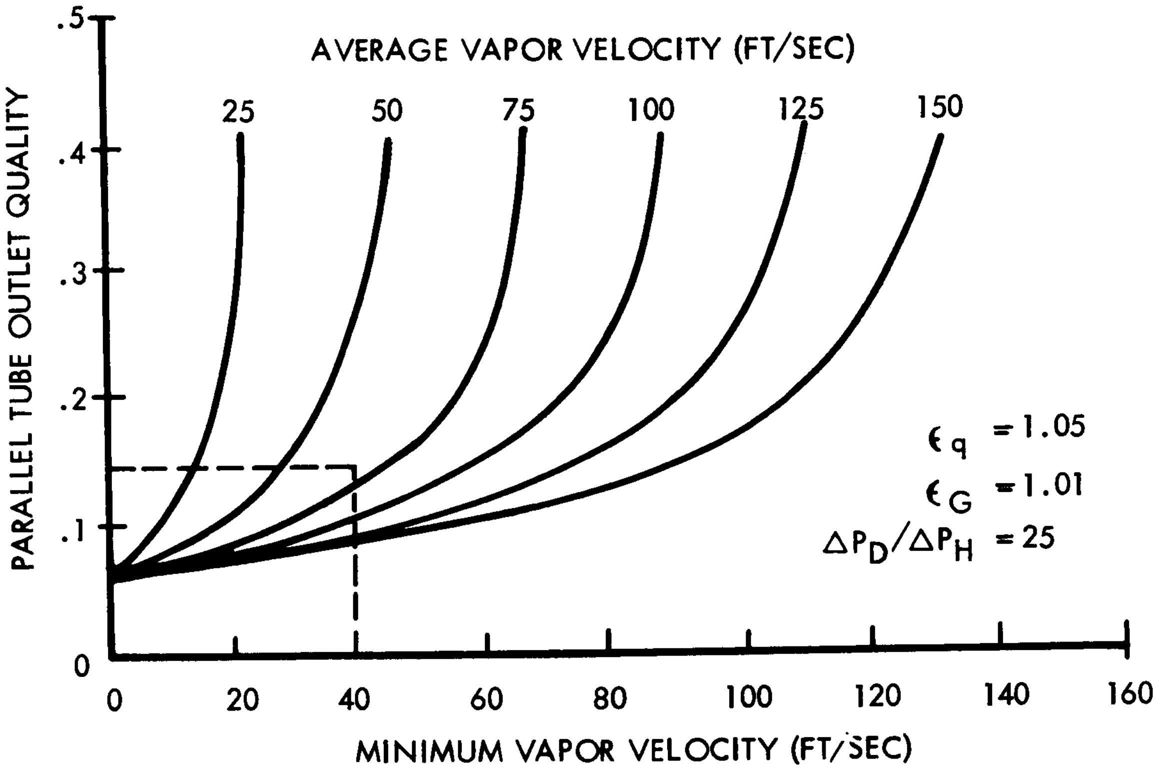


Figure B-6

APPENDIX C

SAMPLE CASES

C-1.0 Design Program, H_2-H_2O Fuel Cell Direct Radiator-Condenser.

C-1.1 Problem Definition

Explore all possible designs for a fuel cell direct radiator-condenser satisfying the following conditions:

System Inputs

hydrogen flow rate	.0562 lb/min
water vapor flow rate	.0738 lb/min
total pressure	60 psia
inlet temperature	800°R
outlet temperature	625°R
pressure drop	.048 psia
sink temperatures	535°R, 500°R

Designer's Inputs

tube, header, fin material	aluminum
geometry	cone, central fin
tube inside diameter range	.20 in. to .22 in. (.01 in. increments)
tube count range	10 to 12 tubes (1 tube increments)
cone diameter at inlet	3.0 ft
cone diameter at outlet	3.4 ft
tube wall thickness	.10 in.
header wall thickness	.03 in.
maximum fin thickness	.20 in.
minimum fin thickness	0 in.
maximum allowable Mach number	.7

Material Properties (at 630°R)

tube, header, fin conductivity	80 BTU/hr-ft-°F
tube, header, fin density	174 lb/ft^3

C-1.2 Input Data Sheet for Fuel Cell Design Sample Case

Figure C-1 shows the input data sheet prepared for the sample case defined in Section C-1.1 (See Section 6.5.1 for detailed instructions for preparing the input cards.)

Each card on the data sheet has been given a sequence number in the left margin to aid the card by card description that follows.

Card 1. General comment card.

Card 2. The 2 in column 2 indicates that two separate thermal environments are to be considered without program restart.

Card 3. Columns 1-10, first sink temperature to be considered is 535°R.

Card 4. Columns 1-10, second sink temperature to be considered is 500°R.

Card 5. Eight ten-digit fields of given input.

Card 6. Eight ten-digit fields of given input.

Card 7. Columns 1-10 and 71-80 show given values for DCMAJ and TFMIN, respectively. Columns 11-20 (LCMIN) and 21-30 (LCMAX) have no values since no length limitation was specified. Columns 31-40 (TIF) and 41-50 (RHOIF) have no values since the cone has a central fin construction and, therefore, inner fin thickness and density are not applicable. Columns 51-60 (WMIN) and 61-70 (WMAX) have no values since no overall width limitation was specified.

Card 8. Columns 1-70 show seven ten-digit fields of given input. Columns 71-80 show no value for WINA O since WINA O is not used in a conical radiator design.

Card 9. Columns 1-10 and 11-20 show no values for WINA F and WINA D, respectively, since these variables are not used in a conical radiator design. Columns 21-30 (TTG) show the given input for tube wall thickness. Columns 31-70 show no values for meteoroid protection data (TAU, -LNPO, MEF, METH) since a given value for tube wall thickness bypasses meteoroid protection. Columns 71-80, value for ALPHS not needed since thermal environment is specified as sink temperatures.

Card 10. Columns 1-10, value for ALPHT not needed since thermal environment is specified as sink temperatures.

Card 11. Columns 1-4 show value for PUNT.

C-1.3 Fuel Cell Design Sample Case Outputs

The outputs for the sample case defined in Section C-1.1 are shown in Figure C-2. The first block in the output is the printout of the fixed input data.

Based on the number of independent variables to be considered, eighteen radiator designs were possible. Each of the two specified sink temperatures heads its group of designs.

Only one of the eighteen possible designs was rejected. When DIIN = .20 in., N = 10 and TS = 535°R, the fin thickness was out of range. The lightest designs occurred at DIIN = .21, N = 12 and DIIN = .20, N = 12 for sink temperatures of 535 and 500°R, respectively. The smallest total area for TS = 535°R and for TS = 500°R occurred at DIIN = .20, N = 11, and at DIIN = .20, N = 10, respectively.

Total running time for the above sample case was 104 seconds on a UNIVAC 1107.

C-2.0 Design Program, Isothermal Direct Radiator-Condenser with Subcooler

C-2.1 Problem Definition

Explore all possible designs for a direct radiator-condenser satisfying the following conditions:

System Inputs

working fluid	water
flow rate	2.34 lb/min
condenser temperature	768°R
condenser pressure	76 psia
inlet quality	.95
inlet temperature	768°R
outlet temperature	735°R
pressure drop	2.0 psi
thermal environment	
incident solar	200 BTU/hr-ft^2
incident thermal	20 BTU/hr-ft^2

Designer's Inputs

geometry	triform, closed sandwich
tube, header material	347 SS
fin material	aluminum
tube inside diameter range	.10 in. to .12 in. (.02 in. increments)
tube count range	50 to 80 tubes (10 tube increments)
fin half-width range	1.0 in. to 4.0 in. (1.0 in. increments)
header wall thickness	.03 in.
maximum allowable Mach number	.80
meteoroid protection	95% chance of no puncture in 500 days
maximum allowable fin thickness	.10 in.
minimum allowable fin thickness	0 in.

Fluid Properties (at 768°R)

gas constant	86 ft-lbf/lbm°R
specific heat ratio	1.31
vapor viscosity	.000011 lb/ft-sec
liquid viscosity	.00012 lb/ft-sec
latent heat	910 BTU/lb
specific heat of liquid	1.03 BTU/lb-°F
liquid density	57.0 lb/ft^3

surface tension	.0035 lb/ft
conductivity of liquid	.395 BTU/hr-ft-^{o}F
specific heat of vapor	.56 BTU/lb-^{o}F

<u>Material Properties</u> (at 768^{o}R)

tube and header density	500 lb/ft^3
fin density	166 lb/ft^3
tube conductivity	10.7 BTU/hr-ft-^{o}F
fin conductivity	125 BTU/hr-ft-^{o}F
fin and tube emittance	.85
fin modulus of elasticity	10 x 10^6 psi
tube modulus of elasticity	3 x 10^7 psi
tube and fin solar absorptivity	.2
tube and fin thermal absorptivity	.85

C-2.2 Input Data Sheet for Isothermal Design Sample Case

Figure C-3 shows the input data sheet prepared for the sample case defined in Section C-2.1. (See Section 6.6.1 for detailed instruction for preparing the input cards.)

Each card on the data sheet has been given a sequence number in the left margin to aid the card by card description that follows.

<u>Card 1</u>. General comment card.

<u>Card 2</u>. The 1 in column 2 indicates that one thermal environment is to be considered without program restart.

<u>Card 3</u>. Columns 1-10, negative number shows that incident fluxes are to be considered. Columns 11-20 show value for the incident solar flux. Columns 21-30 show value for the incident thermal flux.

<u>Card 4</u>. Eight ten-digit fields of given inputs.

<u>Card 5</u>. Eight ten-digit fields of given inputs.

<u>Card 6</u>. Eight ten-digit fields of given inputs.

<u>Card 7</u>. Columns 61-70 (TTG) show no value since tube wall thickness is to be calculated from meteoroid protection data (specified in Column 21-60). Columns 71-80 show value for ALPHS (necessary since heat fluxes are given).

<u>Card 8</u>. Columns 1-10 show value for ALPHT (necessary since heat fluxes are given). Columns 11-20, (DCMIN) and Columns 21-30 (DCMAJ) have no values since this radiator is not a cone. Columns 31-40, (LTMIN) and Columns 41-50 (LTMAX) show no values since no length limitation was imposed. Columns 51-60 (TIF) and 61-70 (RHOIF) show no values since they are applicable to only a cone cylinder configuration. Columns 71-80, (WMIN) has no value since no width

limitation was imposed.

Card 9. Columns 1-10, (WMAX) has no value since no width limitation was imposed. Columns 11-80 show seven ten-digit fields of given inputs.

Card 10. Four ten-digit fields of given input.

Card 11. Columns 1-4 show value for PUNT.

C-2.3 Isothermal Design Sample Case Outputs

The outputs for the sample case defined in Section C-2.1 are shown in Figure C-4.

Three of the thirty-two possible radiator designs were rejected. Combinations

DIIN = .10 in., N = 50, WINA = 1.0 in.
DIIN = .10 in., N = 50, WINA = 2.0 in.
DIIN = .10 in., N = 60, WINA = 1.0 in.

were rejected by the approximate fin efficiency test (higher than 100% efficient fins required).

The lightest design (158.87 lb) occurred for DIIN = .10 in., N = 60 and WINA = 4.0 in. The smallest area (199.5 ft^2) occurred for DIIN = .10 in., N = 50, WINA = 3.0 in.

Total running time for the above sample case was 59 seconds on a UNIVAC 1107.

C-3.0 Design Program, Isothermal Primary/Secondary Direct Radiator-Condenser with Subcooler

C-3.1 Problem Definition

Explore all possible designs for a direct radiator-condenser satisfying the following conditions:

System Inputs

working fluid	mercury
flow rate	13.7 lb/min
condenser temperature	1060°R
condenser pressure	6.6 psia
inlet quality	1.0
inlet temperature	1070°R
outlet temperature	860°R
pressure drop	3.0 psi
sink temperatures	0°R, 400°R

Designer's Inputs

geometry	flat plate, open sandwich
tube, header material	347 SS
fin material	aluminum
tube inside diameter range (at inlet of primary)	.50 in. to .52 in. (.02 in. increments)
tube count range	10 to 14 tubes (in 2 tube increments)
fin half-width range	5.0 in. to 6.0 in. (1.0 in. increments)
header wall thickness	.05 in.
maximum allowable Mach number	.8
meteoroid protection	95% chance of no puncture in 400 days

Fluid Properties (at 1060°R)

gas constant	7.74 ft lbf/lbm°R
specific heat ratio	1.656
vapor viscosity	.0000356 lb/ft-sec
liquid viscosity	.00059 lb/ft-sec
latent heat	127 BTU/lb
specific heat of liquid	.0326 BTU/lb-°F
liquid density	820 lb/ft^3
surface tension	.0326 lb/ft
conductivity of liquid	8.0 BTU/hr-ft-°F
specific heat of vapor	.0249 BTU/lb-°F

Material Properties (at 1060°R)

tube and header density	500.0 lb/ft^3
fin density	166.0 lb/ft^3
tube conductivity	10.7 BTU/hr-ft-°F
fin conductivity	125.0 BTU/hr-ft-°F
fin and tube emittance	.85
fin modulus of elasticity	10 x 10^6 psi
tube modulus of elasticity	3 x 10^7 psi

C-3.2 Input Data Sheet for Primary/Secondary Design Sample Case

Figure C-5 shows the input data sheet prepared for the sample case defined in Section C-3.1. (See Section 6.7.1 for detailed instructions for preparing the input cards.)

Each card on the data sheet has been given a sequence number in the left margin to aid the card by card description that follows.

Card 1. General comment card.

Card 2. The 2 in column 2 indicates that two separate thermal environments are to be considered without program restart.

Card 3. Columns 1-10, the first sink temperature to be considered is $0^{o}R$.

Card 4. Columns 1-10, the second sink temperature to be considered is $400^{o}R$.

Card 5. Eight ten-digit fields of given input.

Card 6. Eight ten-digit fields of given input.

Card 7. Eight ten-digit fields of given input.

Card 8. Columns 61-70 (TTG) show no value since the tube wall thickness is to be calculated from meteoroid protection data (specified in columns 21-60). Columns 71-80 (NUEG) show no value since no minimum gravitational capability was specified.

Card 9. Columns 1-60 (TFMIN, TFMAX, LPMIN, LPMAX, WMIN, WMAX) show no values since no fin thickness, primary condenser length or overall width limitations are specified. Columns 61-80 (TIF, RHIF) show no values since they are not applicable to non-cylinder.

Card 10. Columns 1-10 (LTMAX) show no value since no overall total length limitation is specified. Columns 11-30 (ALPHS, ALPHT) show no values since sink temperatures and not heat fluxes are given. Columns 31-80, five ten-digit fields of given input.

Card 11. Four ten-digit fields of given input.

Card 12. Columns 1-4 show value for PUNT.

C-3.3 Primary/Secondary Design Sample Case Outputs

The outputs for the sample case defined in Section C-3.1 are shown in Figure C-6. In the output the first block of printout shows the fixed input data. Two groups of output follow separated by applicable sink temperatures.

Out of the twenty-four possible designs, eight were rejected.

The following combinations were rejected by the approximate fin efficiency test (fin efficiency greater than 1.0):

TS	DIINP	N	WINA	FEFF
$0^{o}R$	.5 in.	10	5.0 in.	1.09
$400^{o}R$	.5 in.	10	5.0 in.	1.11
$400^{o}R$	.5 in.	10	6.0 in.	1.01

The following combinations were rejected by the fin thickness (primary) limitation check:

TS	DIINP	N	WINA	TFP
0^oR	.50	10	6.0 in.	- .486 in.*
0^oR	.52	10	6.0 in.	.815 in.
400^oR	.52	10	5.0 in.	-3.18 in.*
400^oR	.52	10	6.0 in.	1.128 in.

* Negative due to required fin efficiency slightly higher than 100%.

The combination of TS = 0^oR, DIINP = .52 in., N = 10, WINA = 5.0 in. caused the matrix of the primary condenser to be nonconvergent. This may occur when a negative fin thickness is necessary to satisfy the equation (fin efficiency above 100%).

For both sinks the lightest radiators occurred at DIINP = .52 in., N = 14 and WINA = 5.0.

The smallest radiator area occurred at DIINP = .50 in., N = 12, WINA = 5.0 in. for each sink temperature.

Total running time for the above sample case was 61 seconds on a UNIVAC 1107.

C-4.0 Performance Analysis Program, H_2-H_2O Fuel Cell Direct Radiator-Condenser

C-4.1 Problem Definition

Analyze the performance of a multi-segment fuel cell direct radiator-condenser exposed to two separate sets of different simultaneous sink temperatures, while attempting to attain a specified outlet mixture temperature.

<u>System Inputs</u>

hydrogen flow rate	.0562 lb/min
water vapor flow rate	.0738 lb/min
total pressure	60 psia
inlet temperature	800^oR
desired outlet mixture temperature	625^oR
first set of simultaneous sink temperatures	1) 575^oR 2) 530^oR 3) 500^oR
second set of simultaneous sink temperatures	1) 500^oR 2) 400^oR 3) 300^oR
maximum allowable Mach number	.7

Radiator Geometry

configuration	flat plate, closed sandwich
tube count	15
number of segments	3
tube inside diameter	.21 in.
tube outside diameter	.40 in.
overall width (at inlet)	7.5 ft
overall width (at outlet)	7.5 ft
fin thickness (at inlet)	.005 in.
fin thickness (at outlet)	.005 in.
total length	7.0 ft
material (fins, tubes, headers)	aluminum

Material Properties (near 630°R)

fin and tube conductivity	80 BTU/hr-ft-°F
fin and tube emittance	.92

C-4.2 Input Data Sheet for Fuel Cell Performance Sample Case

Figure C-7 shows the input data sheet prepared for the sample case defined in Section C-4.1. (See Section 6.8.1 for detailed instructions for preparing the input cards.)

Each card on the data sheet has been given a sequence number in the left margin to aid the card by card description that follows.

Card 1. General comment card.

Card 2. The 2 in column 2 indicates that two separate sets of thermal environments are to be considered.

Card 3. The 3 in column 2 indicates that the first thermal environment has three simultaneous sink temperatures or pairs of heat fluxes.

Card 4. Columns 1-10, first sink temperature in first thermal environment is 575°R.

Card 5. Columns 1-10, second sink temperature in first thermal environment is 530°R.

Card 6. Columns 1-10, third sink temperature in first thermal environment is 500°R.

Card 7. The 3 in column 2 indicates that the second thermal environment has three simultaneous sink temperatures or pairs of fluxes.

Card 8. Columns 1-10, first sink temperature in second thermal environment is 500°R.

Card 9. Columns 1-10, second sink temperature in second thermal environment is 400°R.

Card 10. Columns 1-10, third sink temperature in second thermal environment is 300°R.

Card 11. Eight ten-digit fields of given inputs.

Card 12. Columns 1-20 and 41-80 have six ten-digit fields of given inputs. Columns 21-40 (ALPHS and ALPHT) show no values since thermal environments are specified as sink temperatures. Note: Since a non-zero value is given to TOUTM (columns 1-10), segmentation to control mixed outlet temperature is requested.

Card 13. Columns 1-20 and 31-60 have five ten-digit fields of given input. Columns 21-30 (MDTG) and 61-70 (SHIN) show no values since inlet flow conditions are specified by MDG (columns 31-40) and MDVIN (columns 41-50).

Card 14. Columns 1-4 show value for PUNT.

C-4.3 Fuel Cell Performance Sample Case Outputs

The outputs for the sample case defined in Section C-4.1 are shown in Figure C-8.

The first block of outputs following the fixed input block shows the performance of the radiator with all of its three segments in operation. The radiator is exposed to the first set of three sink temperatures (575, 530 and 500°R). The mixed outlet temperature shown (TOMIX) is 613.42°R which is less than the specified target temperature (TOUTM) of 625°R. Removal of segment three is, therefore, demanded.

The second block shows the performance of the radiator with the first two segments operating. Its mixed outlet temperature (TOMIX) is 630.72°R which is higher than the specified target temperature and the run is, therefore, terminated. Operating with all three segments and with segments 1 and 2 brackets the specified outlet mixture temperature of 625°R.

For the second set of three sink temperatures (500, 400, 300°R) three blocks of outputs are shown; the first depicting performance with all three segments operating, the second with the first two segments operating, and the third with only the first segment operating. This resulted in mixed outlet temperatures of 572.86°R, 609.31°R and 636.89°R, respectively. The specified outlet mixture temperature (TOUTM = 625°R) is, therefore, bracketed when operating with the latter two configurations (two segments and one segment).

Total running time for the above sample case was 127 seconds on a UNIVAC 1107.

C-5.0 Performance Analysis Program, Isothermal Direct Radiator-Condenser with Subcooler

C-5.1 First Problem Definition

Analyze the performance of a multi-segment constant inventory isothermal direct radiator-condenser (with subcooler) exposed to different simultaneous heat fluxes, while controlling the outlet mixture temperature by removal of segments.

System Inputs

working fluid	mercury
flow rate	6.5 lb/min
inlet quality	1.0
degrees superheat	0 R^{o}
type of condenser	constant inventory
desired outlet mixture temperature	800^{o}R
type of outlet mixture temperature control	segmentation
thermal environment	
1) solar incident fluxes (segments 1 through 6, respectively)	430, 200, 70, 150, 70, 200 BTU/hr-ft^2
2) thermal incident fluxes (segments 1 through 6, respectively)	0, 0, 30, 60, 30, 0 BTU/hr-ft^2
maximum allowable Mach number	0.8
approximate final condenser temperature guess	1000^{o}R

Radiator Geometry

configuration	cylinder, central fin
tube count	24
number of segments	6
tube inside diameter	.26 in.
tube outside diameter	.50 in.
panel circumference (at inlet)	16.0 ft
panel circumference (at outlet)	16.0 ft
fin thickness (at inlet)	.01 in.
fin thickness (at outlet)	.01 in.
total length	8.5 ft
average condensing length	7.75 ft
tube material	347 SS
fin material	aluminum

Fluid Properties (at 1000^{o}R)

latent heat	127 BTU/lb
molecular weight	200
gas constant	7.74 ft lbf/lbm ^{o}R
reference saturated pressure	5.3 psia
reference saturaged temperature	1041^{o}R
liquid conductivity	8.0 BTU/hr-ft-^{o}F
liquid density	820 lb/ft^3
liquid viscosity	.00059 lb/ft-sec

liquid specific heat	.0326 BTU/lb-$^{\circ}$F
surface tension	.0326 lb/ft
vapor specific heat	.0249 BTU/lb-$^{\circ}$F
vapor viscosity	.0000356 lb/ft-sec
specific heat ratio	1.656

Material Properties (at 1000°R)

solar absorptivity (tube, fin)	.2
thermal absorptivity (tube, fin)	.85
tube thermal conductivity	10.7 BTU/hr-ft-$^{\circ}$F
fin thermal conductivity	125 BTU/hr-ft-$^{\circ}$F
tube and fin thermal emittance	.85

C-5.2 Second Problem Definition

Analyze the performance of a constant pressure, isothermal, direct radiator condenser (with subcooler) exposed to different simultaneous heat fluxes while controlling the outlet mixture temperature by bypassing and mixing working fluid vapor at inlet conditions with mixed liquid condensate.

System Inputs

working fluid	mercury
flow rate	13.1 lb/min
type of condenser	constant pressure
average condensing temperature	1060°R
inlet quality	1.0
degrees superheat	0 R$^{\circ}$
desired outlet mixture temperature	850°R
type outlet mixture temperature control	proportional bypass
thermal environment	
1) solar incident fluxes (segments 1 through 6, respectively)	430, 200, 70, 150, 70, 200 BTU/lb-ft-$^{\circ}$F
2) thermal incident fluxes (segments 1 through 6, respectively)	0, 0, 30, 60, 30, 0 BTU/hr-ft-$^{\circ}$F
maximum allowable Mach number	0.8

Radiator Geometry

configuration	cylinder, central fin
tube count	24
number of segments	6
tube inside diameter	.26 in.
tube outside diameter	.50 in.
circumference (at inlet)	16.0 ft
circumference (at outlet)	16.0 ft
fin thickness (at inlet)	.01 in.
fin thickness (at outlet)	.01 in.

total length	9.0 ft
tube material	347 SS
fin material	aluminum

Fluid Properties (at 1060°R)

latent heat	127 BTU/hr
molecular weight	200
gas constant	7.74 ft lbf/lbm °R
reference saturated pressure	5.3 psia
reference saturated temperature	1041°R
liquid conductivity	8.0 BTU/hr-ft-°F
liquid density	820 lb/ft^3
liquid viscosity	.00059 lb/ft-sec
liquid specific heat	.0326 BTU/lb °F
surface tension	.0326 lb/ft
vapor specific heat	.0249 BTU/lb °F
vapor viscosity	.0000356 lb/ft-sec
specific heat ratio	1.656

Material Properties (at 1060°R)

solar absorptivity (tube, fin)	.20
thermal absorptivity (tube, fin)	.85
tube conductivity	10.7 BTU/hr-ft-°F
fin conductivity	125.0 BTU/hr-ft-°F
tube and fin emittance	.85

C-5.3 Isothermal Performance Input Data Sheet for Sample Cases

Figure C-9 shows the input data sheet prepared for both sample cases defined in Section C-5.1 and C-5.2. The two sets of inputs can be run without program restart since both use the same program. (See Section 6.9.1 for detailed instructions for preparing the input cards.)

Each card on the data sheet has been given a sequence number in the left margin to aid the card by card description that follows.

Card 1. General comment card for first set of inputs.

Card 2. The 1 in column 2 indicates that only one set of simultaneous thermal environments is to be considered.

Card 3. The 6 in column 2 indicates that these are six simultaneous sink temperatures or heat fluxes.

Card 4 through Card 9. The negative numbers in columns 1-10 show that incident solar and thermal heat fluxes are to be considered. Columns 11-20 show incident solar flux values; columns 21-30 show incident thermal flux values.

Card 10. Eight ten-digit fields of given inputs.

Card 11. Eight ten-digit fields of given inputs.

Card 12. Eight ten-digit fields of given inputs.

Card 13. Columns 1-60, six ten-digit fields of given inputs; columns 61-70, the value for NOS shows that four different heat flux combinations were used. Columns 71-80, the zero value for PBP shows that mixed outlet temperature control is achieved by segment action.

Card 14. Columns 1-20 and 31-60, five ten-digit fields of inputs; columns 21-30, the zero value for TCG shows that a constant inventory system is analyzed.

Card 15. Columns 1-4, value for PUNT.

Card 16. General comment card for second set of inputs.

Card 17. The 1 in column 2 indicates that one set of simultaneous thermal environments is to be considered.

Card 18. The 6 in column 2 indicates that there are six simultaneous sink temperatures or heat fluxes.

Card 19 through Card 24. The negative numbers in columns 1-10 show that incident solar and thermal heat fluxes are to be considered. Columns 11-20 show incident solar flux values; columns 21-30 show incident thermal flux values.

Card 25. Eight ten-digit fields of given inputs.

Card 26. Columns 1-10 and 21-80, seven ten-digital fields of given inputs; columns 11-20, the zero value for LCG indicates that the system is of the constant pressure type.

Card 27. Eight ten-digit fields of given inputs.

Card 28. Columns 1-60, six ten-digit fields of given inputs; columns 61-70, the value for NOS shows that four different heat flux combinations were used. Columns 71-80, the 1.0 for PBP shows that the outlet mixture temperature is to be controlled by proportionally bypassing and mixing of vapor with the outlet condensate.

Card 29. Columns 1-30 and 41-60, five ten-digit fields of given inputs. Columns 31-40, since the average condensing temperature (TCG) is given in a constant pressure system, no approximate average condensing temperature is needed and the value of zero must be assigned to TCAPG.

Card 30. Columns 1-4, value for PUNT.

C-5.4 Isothermal Performance Sample Case Outputs

The outputs of the sample cases defined in Sections C-5.1 and C-5.2 are shown in Figure C-10.

The outputs for the two separate sets of inputs are separated by the fixed input block printout. The output for the first set of inputs (segmentation; constant inventory) is shown first. It consists of the fixed input block followed by four groups of output. Each group has the average of the sink temperatures of the operating segments specified.

The first group shows the radiator operating with all six segments. The mixed outlet temperature (TOMIX) is 643.4°R which is less than the specified target temperature (TMIXG) of 800°R, therefore, automatic segmenting should occur. The next three blocks of output show the radiator operating with 5, 4, and 3 segments, respectively. The corresponding mixed outlet temperatures (TOMIX) are 675.7°R, 736.7°R and 817.3°R. With three segments in operation, the value for TMIXG was exceeded and the anlysis completed.

In all but the last group the Mach number specified (FSV) is exceeded as indicated by the message - MACH . . . IS TOO HIGH . . . WARNING. However, since these groups did not produce a proper outlet temperature, no problem exists. The zero value for TMIXX is meaningless since this variable is not applicable to cases using segmentation for temperature control.

The output for the second set of inputs (proportional bypass; constant pressure) follows the second block of fixed input printout. The output consists of four groups with all segments operating but with different total mass flows through the condenser tubes.

The first three groups of output show mathematically correct solutions which may not be physically possible. This is true for the first group where TMIXX is higher than the temperature of the bypassed vapor (THETA for the first group equals .25).

The second group used a negative THETA (-.01857) which is also physically impossible. The third and fourth groups show physically possible solutions, but only the last group contains the final answer where the value for TMIXX (846.7°R) falls within 1.0% of the specified target temperature of TMIXG = 850°R.

Total running time for the above sample case (two sets of inputs) was 185 seconds on a UNIVAC 1107.

SAMPLE INPUT DATA SHEET - FUEL CELL DESIGN PROGRAM

FORTRAN DATA SHEET

COLS	1 - 10	11 - 20	21 - 30	31 - 40	41 - 50	51 - 60	61 - 70	71 - 80
1	SAMPLE CA	SE NØ 1, C	ENTRAL FIN	CØNE FUEL	CELL DIREC	T RADIATØ	R	
2	NO OF TS's 02							
3	TS 535.							
4	TS 500.							
5	MDG .0562	MDVIN .0738	PM 60.	TIN 800.	TOUT 625.	DPTOT .048	KTH 80.	KF 80.
6	RHOF 174.	RHOT 174.	RHOH 174.	TH .03	ET .92	EF .92	FSY .70	DCMIN 3.0
7	DCMAJ 3.4	LCMIN	LCMAX	TIF	RHOIF	WMAX	WMIN	TFMIN 0.0
8	TFMAX .20	DIINO .20	DIINF .22	DIIND .01	NO 10.	NF 12.	ND 1.0	WINA O
9	WINA F	WINA D	TTG .10	TAU	-LNPO	MEF	METH	ALPHS
10	ALPHT 0.0							
11	PUNT 1512							

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TITLE SAMPLE INPUT SHEET	ENGR.
DESIGN PROGRAM, $H_2 - H_2O$	DATE
FUEL CELL DIRECT R/C	PAGE 1 OF 1 PAGES
PROJECT	JOB NO.

EDP SERVICES

Figure C-1

SAMPLE OUTPUT
FUEL CELL DESIGN PROGRAM

SAMPLE CASE NO. 1. CENTRAL FIN CONE FUEL CELL DIRECT RADIATOR
DESIGN PROGRAM,H2 - H20 FUEL CELL , DIRECT R/C
FIXED INPUT

MDG	MDVIN	PM	TIN	TOUT	DPTOT	KTH	KF	RHOF	RHHT
LBS/MIN	LBS/MIN	PSIA	DEG R	DEG R	PSI	B/HR FT F	B/HR FT F	LBS/CU FT	LBS/CU FT
.0562	.0738	60.0000	800.0000	625.0000	.0480	80.0000	80.0000	174.0000	174.0000
RHOH	TH	ET	EF	FSV	DCMIN	DCMAJ	LCMIN	LCMAX	TIF
LBS/CU FT	INCH				FT	FT	FT	FT	INCH
174.0000	.0300	.9200	.9200	.7000	3.0000	3.4000	-.0000	-.0000	-.0000
RHOIF	WMAX	WMIN	TFMIN	TFMAX	DIINO	DIINF	DIIND	N O	N F
LB/CU.FT	FT	FT	INCH	INCH	INCH	INCH	INCH		
-.0000	-.0000	-.0000	-.0000	.2000	.2000	.2200	.0100	10.0000	12.0000

N D	WINA O	WINA F	WINA D	TTG	TAU	-LNPO	MEF	METH	ALPHB	ALPHT
	INCH	INCH	INCH	INCH	DAYS		PSI	PSI		
1.	-.0000	-.0000	-.0000	.1000	-.0000	-.0000	-0.	-0.	-.0000	.0000

PUNT IS 1512

18 INPUT COMBINATIONS REQUESTED

TINSA IS 642.1

TS IS 535.0 DEG R

DIIN .2000 N 10.0000 WINA -.0000 TF .41566 OUT OF RANGE

DIIN	N	WINA	SHIN	VMIN	DIINH	DIHA	WBRIX
INCH		INCH		FT/SEC	INCH	INCH	FT
.20000	11.00000	-.00000	1.31317	32.15091	.46897	.33166	9.42000
DPIH	MDVE	SHOUT	VME	DIFHE	DEHA	WBARE	DPEH
PSI	LBS/MIN		FT/SEC	INCH	IN.	FT	PSI
.00996	.04564	.81205	23.90511	.46897	.33166	10.67600	.00771
DIINX	TTX	DDINX	LC	DPLC	WINX	WOUX	VF
INCH	INCH	INCH	FT	PSI	INCH	INCH	INCH
.19995	.10000	.39995	5.10320	.02799	4.94093	5.62639	.02801
T10	T20	T30	QTOT	QFTOT	QTTOT	FEF1	FEF2
DEG R	DEG R	DEG R	B/HR	B/HR	B/HR		
639.29685	633.56957	627.85651	4213.85200	3920.29890	293.55310	.66323	.65145
FEF3	NUE	MT	MF	MIF	MHS	MCR	ACR
	NO OF GS	LBS	LBS	LBS	LBS	LBS	SQ FT
.64032	.24674	6.38689	18.62872	.00000	.82707	25.84267	51.27692

DIIN	N	WINA	SHIN	VMIN	DIINH	DIHA	WBRIX
INCH		INCH		FT/SEC	INCH	INCH	FT
.20000	12.00000	-.00000	1.31317	29.47167	.48982	.34641	9.42000
DPIH	MDVE	SHOUT	VME	DIFHE	DEHA	WBARE	DPEH

FIGURE C-2

PSI	LBS/MIN		FT/SEC	INCH	IN.	FT	PSI
.00790	.04564	.81205	21.91302	.48982	.34641	10.67600	.00612
DIINX	TTX	DOINX	LC	DPLC	WINX	WOUX	TF
INCH	INCH	INCH	FT	PSI	INCH	INCH	INCH
.19995	.10000	.39995	6.36810	.03201	4.51252	5.14086	.01064
T10	T20	T30	QTOT	QFTOT	QTTOT	FEF1	FEF2
DEG R	DEG R	DEG R	B/HR	B/HR	B/HR		
639.28056	633.53065	627.84354	4213.85200	3812.50710	401.34491	.51946	.50626
FEF3	NUE	MT	MF	MIF	MHS	MCR	ACR
	NO OF GS	LBS	LBS	LBS	LBS	LBS	SQ FT
.49381	.21645	8.69455	9.47569	.00000	.86079	19.03103	63.98671
DIIN	N	WINA	SHIN	VMIN	DIINH	DIHA	WBR1X
INCH		INCH		FT/SEC	INCH	INCH	FT
.21000	10.00000	-.00000	1.31317	32.07801	.46950	.33204	9.42000
DPIH	MDVE	SHOUT	VME	DIFHF	DEHA	WBARF	DPFH
PSI	LBS/MIN		FT/SEC	INCH	IN.	FT	PSI
.00990	.04564	.81205	23.85091	.46950	.33204	10.67600	.00766
DIINX	TTX	DOINX	LC	DPLC	WINX	WOUX	TF
INCH	INCH	INCH	FT	PSI	INCH	INCH	INCH
.20995	.10000	.40995	5.66264	.02810	5.45003	6.20403	.02247
T10	T20	T30	QTOT	QFTOT	QTTOT	FEF1	FEF2
DEG R	DEG R	DEG R	B/HR	B/HR	B/HR		
639.28933	633.55168	627.85055	4213.85200	3909.90040	303.95160	.59598	.58336
FEF3	NUE	MT	MF	MIF	MHS	MCR	ACR
	NO OF GS	LBS	LBS	LBS	LBS	LBS	SQ FT
.57146	.23868	6.65754	17.90259	.00000	.82793	25.38806	56.89825
DIIN	N	WINA	SHIN	VMIN	DIINH	DIHA	WBR1X
INCH		INCH		FT/SEC	INCH	INCH	FT
.21000	11.00000	-.00000	1.31317	29.16183	.49242	.34825	9.42000
DPIH	MDVE	SHOUT	VME	DIFHF	DEHA	WBARF	DPFH
PSI	LBS/MIN		FT/SEC	INCH	IN.	FT	PSI
.00768	.04564	.81205	21.68264	.49242	.34825	10.67600	.00595
DIINX	TTX	DOINX	LC	DPLC	WINX	WOUX	TF
INCH	INCH	INCH	FT	PSI	INCH	INCH	INCH
.20995	.10000	.40995	7.19073	.03244	4.93593	5.62139	.00927
T10	T20	T30	QTOT	QFTOT	QTTOT	FEF1	FEF2
DEG R	DEG R	DEG R	B/HR	B/HR	B/HR		
639.77329	633.51296	627.83764	4213.85200	3787.38220	426.46979	.45654	.44371
FEF3	NUE	MT	MF	MIF	MHS	MCR	ACR
	NO OF GS	LBS	LBS	LBS	LBS	LBS	SQ FT
.43167	.20689	9.29953	9.35180	.00000	.86499	19.51632	72.25241
DIIN	N	WINA	SHIN	VMIN	DIINH	DIHA	WBR1X
INCH		INCH		FT/SEC	INCH	INCH	FT
.21000	12.00000	-.00000	1.31317	26.73168	.51432	.36373	9.42000
DPIH	MDVE	SHOUT	VME	DIFHF	DEHA	WBARF	DPFH
PSI	LBS/MIN		FT/SEC	INCH	IN.	FT	PSI
.00609	.04564	.81205	19.87575	.51432	.36373	10.67600	.00472
DIINX	TTX	DOINX	LC	DPLC	WINX	WOUX	TF
INCH	INCH	INCH	FT	PSI	INCH	INCH	INCH

FIGURE C-2 (cont'd)

.20995	.10000	.40995	8.60003	.03557	4.50753	5.13586	.00488
T10	T20	T30	QTOT	QFTOT	QTTOT	FEF1	FEF2
DEG R	DEG R	DEG R	B/HR	B/HR	B/HR		
639.26350	633.48933	627.82975	4213.85200	3656.04100	557.81104	.36975	.35805
FEF3	NUE	MT	MF	MIF	MHS	MCR	ACR
	NO OF GS	LBS	LBS	LBS	LBS	LBS	SQ FT
.34714	.18202	12.13327	5.65928	.00000	.90040	18.89295	86.41312
DIIN	N	WINA	SHIN	VMIN	DIINH	DIHA	WBR1X
INCH		INCH		FT/SEC	INCH	INCH	FT
.22000	10.00000	-.00000	1.31317	29.22810	.49186	.34785	9.42000
DPIH	MDVE	SHOUT	VME	DIFHE	DEHA	WBARE	DPEH
PSI	LBS/MIN		FT/SEC	INCH	IN.	FT	PSI
.00773	.04564	.81205	21.73192	.49186	.34785	10.67600	.00598
DIINX	TTX	DOINX	LC	DPLC	WINX	WOUX	TF
INCH	INCH	INCH	FT	PSI	INCH	INCH	INCH
.21995	.10000	.41995	7.85179	.03235	5.44503	6.19903	.00915
T10	T20	T30	QTOT	QFTOT	QTTOT	FEF1	FEF2
DEG R	DEG R	DEG R	B/HR	B/HR	B/HR		
639.26914	633.50313	627.83436	4213.85200	3779.78740	434.06451	.41658	.40426
FEF3	NUE	MT	MF	MIF	MHS	MCR	ACR
	NO OF GS	LBS	LBS	LBS	LBS	LBS	SQ FT
.39273	.20185	9.52911	10.09801	.00000	.86409	20.49120	78.89483
DIIN	N	WINA	SHIN	VMIN	DIINH	DIHA	WBR1X
INCH		INCH		FT/SEC	INCH	INCH	FT
.22000	11.00000	-.00000	1.31317	26.57100	.51587	.36483	9.42000
DPIH	MDVE	SHOUT	VME	DIFHE	DEHA	WBARE	DPEH
PSI	LBS/MIN		FT/SEC	INCH	IN.	FT	PSI
.00600	.04564	.81205	19.75629	.51587	.36483	10.67600	.00484
DIINX	TTX	DOINX	LC	DPLC	WINX	WOUX	TF
INCH	INCH	INCH	FT	PSI	INCH	INCH	INCH
.21995	.10000	.41995	9.54678	.03576	4.93094	5.61639	.00461
T10	T20	T30	QTOT	QFTOT	QTTOT	FEF1	FEF2
DEG R	DEG R	DEG R	B/HR	B/HR	B/HR		
639.26025	633.48158	627.82717	4213.85200	3631.79550	582.05646	.33018	.31935
FEF3	NUE	MT	MF	MIF	MHS	MCR	ACR
	NO OF GS	LBS	LBS	LBS	LBS	LBS	SQ FT
.30929	.17546	12.74482	6.16194	.00000	.90291	19.80967	95.92605
DIIN	N	WINA	SHIN	VMIN	DIINH	DIHA	WBR1X
INCH		INCH		FT/SEC	INCH	INCH	FT
.22000	12.00000	-.00000	1.31317	24.35675	.53881	.38105	9.42000
DPIH	MDVE	SHOUT	VME	DIFHE	DEHA	WBARE	DPEH
PSI	LBS/MIN		FT/SEC	INCH	IN.	FT	PSI
.00476	.04564	.81205	18.10993	.53881	.38105	10.67600	.00358
DIINX	TTX	DOINX	LC	DPLC	WINX	WOUX	TF
INCH	INCH	INCH	FT	PSI	INCH	INCH	INCH
.21995	.10000	.41995	11.12965	.03821	4.50253	5.13086	.00262
T10	T20	T30	QTOT	QFTOT	QTTOT	FEF1	FEF2
DEG R	DEG R	DEG R	B/HR	B/HR	B/HR		
639.25452	633.46905	627.82300	4213.85200	3472.56770	741.28424	.27160	.26221

FIGURE C-2 (cont'd)

FFF3	NUE	MT	MF	MIF	MHS	MCR	ACR
	NO OF GS	LBS	LBS	LBS	LBS	LBS	SQ FT
.25354	.15459	16.20866	4.06451	.00000	.94001	21.21318	111.83074

TS IS 500.0 DEG R

DIIN	N	WINA	SHIN	VMIN	DIINH	DIHA	WBR1X
INCH		INCH		FT/SEC	INCH	INCH	FT
.20000	10.00000	-.00000	1.31317	35.36601	.44715	.31623	9.42000
DPIH	MDVE	SHOUT	VME	DIFHF	DEHA	WBARF	DPEH
PSI	LBS/MIN		FT/SEC	INCH	IN.	FT	PSI
.01283	.04564	.81205	26.29562	.44715	.31623	10.67600	.00994
DIINX	TTX	DOINX	LC	DPLC	WINX	WOUX	TF
INCH	INCH	INCH	FT	PSI	INCH	INCH	INCH
.20028	.10000	.40028	3.64508	.02239	5.45486	6.20886	.05136
TIN	T20	T30	QTOT	QFTOT	QTTOT	FEF1	FEF2
DEG R	DEG R	DEG R	B/HR	B/HR	B/HR		
639.33519	633.68325	627.89440	4213.85200	3977.31570	236.53625	.75271	.74409
FFF3	NUE	MT	MF	MIF	MHS	MCR	ACR
	NO OF GS	LBS	LBS	LBS	LBS	LBS	SQ FT
.73635	.28677	4.15184	26.36795	.00000	.79177	31.31156	36.62581

DIIN	N	WINA	SHIN	VMIN	DIINH	DIHA	WBR1X
INCH		INCH		FT/SEC	INCH	INCH	FT
.20000	11.00000	-.00000	1.31317	32.15091	.46897	.33166	9.42000
DPIH	MDVE	SHOUT	VME	DIFHF	DEHA	WBARF	DPEH
PSI	LBS/MIN		FT/SEC	INCH	IN.	FT	PSI
.00996	.04564	.81205	23.90511	.46897	.33166	10.67600	.00771
DIINX	TTX	DOINX	LC	DPLC	WINX	WOUX	TF
INCH	INCH	INCH	FT	PSI	INCH	INCH	INCH
.19995	.10000	.39995	5.10320	.02799	4.94093	5.62639	.01256
TIN	T20	T30	QTOT	QFTOT	QTTOT	FEF1	FEF2
DEG R	DEG R	DEG R	B/HR	B/HR	B/HR		
639.32050	633.65885	627.88627	4213.85200	3846.70180	367.15027	.52318	.51046
FFF3	NUE	MT	MF	MIF	MHS	MCR	ACR
	NO OF GS	LBS	LBS	LBS	LBS	LBS	SQ FT
.49866	.24674	6.38686	8.99691	.00000	.82707	16.21084	51.27692

DIIN	N	WINA	SHIN	VMIN	DIINH	DIHA	WBR1X
INCH		INCH		FT/SEC	INCH	INCH	FT
.20000	12.00000	-.00000	1.31317	29.47167	.48982	.34641	9.42000
DPIH	MDVE	SHOUT	VME	DIFHF	DEHA	WBARF	DPEH
PSI	LBS/MIN		FT/SEC	INCH	IN.	FT	PSI
.00790	.04564	.81205	21.91302	.48982	.34641	10.67600	.00612
DIINX	TTX	DOINX	LC	DPLC	WINX	WOUX	TF
INCH	INCH	INCH	FT	PSI	INCH	INCH	INCH
.19995	.10000	.39995	6.36810	.03201	4.51253	5.14086	.00575
TIN	T20	T30	QTOT	QFTOT	QTTOT	FEF1	FEF2
DEG R	DEG R	DEG R	B/HR	B/HR	B/HR		
639.30808	633.62723	627.87573	4213.85200	3712.37170	501.48022	.40617	.39415

FIGURE C-2 (cont'd)

FEF3	NUE	MT	MF	MIF	MHS	MCR	ACR
	NO OF GS	LBS	LBS	LBS	LBS	LBS	SQ FT
.38304	.21645	8.69451	5.11905	.00000	.86079	14.67434	63.98671

DIIN	N	WINA	SHIN	VMIN	DIINH	DIHA	WBR1X
INCH		INCH		FT/SEC	INCH	INCH	FT
.21000	10.00000	-.00000	1.31317	32.07801	.46950	.33204	9.42000
DPIH	MDVE	SHOUT	VME	DIFHE	DEHA	WBARF	DPEH
PSI	LBS/MIN		FT/SEC	INCH	IN.	FT	PSI
.00990	.04564	.81205	23.85091	.46950	.33204	10.67600	.00766
DIINX	TTX	DOINX	LC	DPLC	WINX	WOUX	TF
INCH	INCH	INCH	FT	PSI	INCH	INCH	INCH
.20995	.10000	.40995	5.66264	.02810	5.45003	6.20403	.01162
T10	T20	T30	QTOT	QFTOT	QTTOT	FEF1	FEF2
DEG R	DEG R	DEG R	B/HR	B/HR	B/HR		
639.31507	633.64524	627.88174	4213.85200	3833.83470	380.01727	.46936	.45689
FEF3	NUE	MT	MF	MIF	MHS	MCR	ACR
	NO OF GS	LBS	LBS	LBS	LBS	LBS	SQ FT
.44534	.23868	6.65750	9.26256	.00000	.82793	16.74799	56.89825

DIIN	N	WINA	SHIN	VMIN	DIINH	DIHA	WBR1X
INCH		INCH		FT/SEC	INCH	INCH	FT
.21000	11.00000	-.00000	1.31317	29.16183	.49242	.34825	9.42000
DPIH	MDVE	SHOUT	VME	DIFHE	DEHA	WBARF	DPEH
PSI	LBS/MIN		FT/SEC	INCH	IN.	FT	PSI
.00768	.04564	.81205	21.68264	.49242	.34825	10.67600	.00595
DIINX	TTX	DOINX	LC	DPLC	WINX	WOUX	TF
INCH	INCH	INCH	FT	PSI	INCH	INCH	INCH
.20995	.10000	.40995	7.19073	.03244	4.93594	5.62139	.00517
T10	T20	T30	QTOT	QFTOT	QTTOT	FEF1	FEF2
DEG R	DEG R	DEG R	B/HR	B/HR	B/HR		
639.30368	633.61628	627.87208	4213.85200	3681.15380	532.69818	.35604	.34491
FEF3	NUE	MT	MF	MIF	MHS	MCR	ACR
	NO OF GS	LBS	LBS	LBS	LBS	LBS	SQ FT
.33464	.20689	9.29948	5.20938	.00000	.86499	15.37385	72.25241

DIIN	N	WINA	SHIN	VMIN	DIINH	DIHA	WBR1X
INCH		INCH		FT/SEC	INCH	INCH	FT
.21000	12.00000	-.00000	1.31317	26.73168	.51432	.36373	9.42000
DPIH	MDVE	SHOUT	VME	DIFHE	DEHA	WBARF	DPEH
PSI	LBS/MIN		FT/SEC	INCH	IN.	FT	PSI
.00609	.04564	.81205	19.87575	.51432	.36373	10.67600	.00472
DIINX	TTX	DOINX	LC	DPLC	WINX	WOUX	TF
INCH	INCH	INCH	FT	PSI	INCH	INCH	INCH
.20995	.10000	.40995	8.60003	.03557	4.50753	5.13586	.00276
T10	T20	T30	QTOT	QFTOT	QTTOT	FEF1	FEF2
DEG R	DEG R	DEG R	B/HR	B/HR	B/HR		
639.29740	633.59948	627.86648	4213.85200	3517.45960	696.39245	.28529	.27570
FEF3	NUE	MT	MF	MIF	MHS	MCR	ACR
	NO OF GS	LBS	LBS	LBS	LBS	LBS	SQ FT
.26690	.18202	12.13319	3.31259	.00000	.90040	16.34618	86.41312

FIGURE C-2 (cont'd)

DIIN	N	WINA	SHIN	VMIN	DIINH	DIHA	WBR1X
INCH		INCH		FT/SEC	INCH	INCH	FT
.22000	10.00000	-.00000	1.31317	29.22810	.49186	.34785	9.42000
DPIH	MDVE	SHOUT	VME	DIFHE	DEHA	WBARF	DPEH
PSI	LBS/MIN		FT/SEC	INCH	IN.	FT	PSI
.00773	.04564	.81205	21.73192	.49186	.34785	10.67600	.00598
DIINX	TTX	DOINX	LC	DPLC	WINX	WOUX	TF
INCH	INCH	INCH	FT	PSI	INCH	INCH	INCH
.21994	.10000	.41994	7.85179	.03235	5.44503	6.19903	.00518
T10	T20	T30	QTOT	QFTOT	QTTOT	FEF1	FEF2
DEG R	DEG R	DEG R	B/HR	B/HR	B/HR		
639.30124	633.61058	627.87018	4213.85200	3671.74130	542.11072	.32452	.31409
FEF3	NUE	MT	MF	MIF	MHS	MCR	ACR
	NO OF GS	LBS	LBS	LBS	LBS	LBS	SQ FT
.30449	.20185	9.52905	5.71541	.00000	.86409	16.10854	78.89483

DIIN	N	WINA	SHIN	VMIN	DIINH	DIHA	WBR1X
INCH		INCH		FT/SEC	INCH	INCH	FT
.22000	11.00000	-.00000	1.31317	26.57100	.51587	.36483	9.42000
DPIH	MDVE	SHOUT	VME	DIFHE	DEHA	WBARF	DPEH
PSI	LBS/MIN		FT/SEC	INCH	IN.	FT	PSI
.00600	.04564	.81205	19.75629	.51587	.36483	10.67600	.00464
DIINX	TTX	DOINX	LC	DPLC	WINX	WOUX	TF
INCH	INCH	INCH	FT	PSI	INCH	INCH	INCH
.21994	.10000	.41994	9.54678	.03576	4.93094	5.61639	.00262
T10	T20	T30	QTOT	QFTOT	QTTOT	FEF1	FEF2
DEG R	DEG R	DEG R	B/HR	B/HR	B/HR		
639.29512	633.59567	627.86519	4213.85200	3487.26590	726.58612	.25418	.24545
FEF3	NUE	MT	MF	MIF	MHS	MCR	ACR
	NO OF GS	LBS	LBS	LBS	LBS	LBS	SQ FT
.23747	.17546	12.74473	3.51063	.00000	.90291	17.15827	95.92605

DIIN	N	WINA	SHIN	VMIN	DIINH	DIHA	WBR1X
INCH		INCH		FT/SEC	INCH	INCH	FT
.22000	12.00000	-.00000	1.31317	24.35675	.53881	.38105	9.42000
DPIH	MDVE	SHOUT	VME	DIFHE	DEHA	WBARF	DPEH
PSI	LBS/MIN		FT/SEC	INCH	IN.	FT	PSI
.00476	.04564	.81205	18.10993	.53881	.38105	10.67600	.00368
DIINX	TTX	DOINX	LC	DPLC	WINX	WOUX	TF
INCH	INCH	INCH	FT	PSI	INCH	INCH	INCH
.21995	.10000	.41995	11.12965	.03821	4.50253	5.13086	.00147
T10	T20	T30	QTOT	QFTOT	QTTOT	FEF1	FEF2
DEG R	DEG R	DEG R	B/HR	B/HR	B/HR		
639.29149	633.58547	627.86179	4213.85200	3288.82200	925.03003	.20621	.19889
FEF3	NUE	MT	MF	MIF	MHS	MCR	ACR
	NO OF GS	LBS	LBS	LBS	LBS	LBS	SQ FT
.19220	.15459	16.20855	2.29013	.00000	.94001	19.43869	111.83074

FIGURE C-2 (cont'd)

SAMPLE INPUT DATA SHEET - ISOTHERMAL DESIGN PROGRAM

FORTRAN DATA SHEET

Card	COLS 1 - 10	11 - 20	21 - 30	31 - 40	41 - 50	51 - 60	61 - 70	71 - 80
1	SAMPLE CASE NØ 2, CLØSED SANDWICH TRIFØRM RADIATØR. WØRKING FLUID-WATER							
	Nº OF HEAT FLUX PAIRS							
2	01							
		QIS	QIT					
3	-1.0	200.	20.					
	PC	TC	MDT	XIN	DPTOT	TOUT	R	GAMMA
4	76.	768.	2.34	.95	2.	735.	86.	1.31
	VISV	VISL	HFG	CL	RHOL	SVFT	KC	RHOT
5	.0000110	.000120	910.	1.03	57.	.0035	.395	500.
	RHOF	KTH	KF	RHOH	TH	FSV	ET	EF
6	166.	10.7	125.	500.	.03	.80	.85	.85
	CV	TIN	TAU	-LNPO	MEF	METH	TTG	ALPHS
7	.56	768.	500.	.05113	10000000.	30000000.		.2
	ALPHT	DCMIN	DCMAT	LTMIN	LTMAX	TIF	RHOIF	WMIN
8	.85							
	WMAX	TFMIN	TFMAX	DMIN	DMAX	DDEL	NMIN	NMAX
9		0.0	.100	.10	.12	.02	50.	80.
	NDEL	WIN MIN	WIN MAX	WIN DEL				
10	10.	1.0	4.0	1.0				
	PUNT							
11	3312							

X-300 PRINTED IN U.S.A.

TITLE SAMPLE INPUT SHEET	ENGR.	PROJECT
DESIGN PROGRAM, ISOTHERMAL	DATE	JOB NO.
DIRECT R/C w/SC	PAGE 1 OF 1 PAGES	

EDP SERVICES

Figure C-3

SAMPLE OUTPUT
ISOTHERMAL DESIGN PROGRAM

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SAMPLE CASE NO. 2, CLOSED SANDWICH TRIFORM RADIATOR, WORKING FLUID-WATER

PUNT IS  3312

DESIGN PROGRAM  ISO  R/C  W/SC
FIXED INPUT
       PC          TC         MDT         XIN       DPTOT        TOUT           R       GAMMA        VISV        VISL
     PSIA       DEG R     LBS/MIN                     PSI       DEG R        FT/R              LB/FT SEC   LB/FT SEC
  76.0000    768.0000      2.3400       59500      2.0000    735.0000     86.0000      1.3100  .00001100   .00012000
      HFG          CL        RHOL        SUFT          KC        RHOT        RHOF         KTH          KF        RHOH
     B/LB    B/LB F   LBS/CU FT      LBS/FT  B/HR FT F  LBS/CU FT  LBS/CU FT  B/HR FT F  B/HR FT F  LBS/CU FT
 910.0000      1.0300     57.0000       .0035       .3950    500.0000    166.0000     10.7000    125.0000    500.0000
       TH         FSV          FT          EF          CV         TIN         TAU       -LNPO         MEF        METH
     INCH                                          B/LB F       DEG R        DAYS                     PSI         PSI
    .0300       .8000       .8500       .8500       .5600    768.0000    500.0000       .0513  10000000.   30000000.
      TTG       ALPHS       ALPHT       DCMIN       DCMAJ       LTMIN       LTMAX         TIF       RHOIF        WMIN
     INCH                                  FT          FT          FT          FT        INCH   LBS/CU FT          FT
   -.0000       .2000       .8500      -.0000      -.0000      -.0000      -.0000      -.0000      -.0000      -.0000
     WMAX       TFMIN       TFMAX        DMIN        DMAX        DDEL        NMIN        NMAX        NDEL     WIN MIN     WIN MAX     WIN DEL
       FT        INCH        INCH        INCH        INCH        INCH                                           INCH        INCH        INCH
   -.0000      -.0000       .1000       .1000       .1200       .0200     50.0000     80.0000     10.0000      1.0000      4.0000      1.0000

PPWR IS       .00034790 HP

TS IS       444.7 DEG R

DIIN    .10000       N      50.00000       WINA     1.00000       FEFF     2.11122      OUT OF RANGE
DIIN    .10000       N      50.00000       WINA     2.00000       FEFF     1.15583      OUT OF RANGE

              DIIN                 N              WINA              VIN             DIINH             D1HA              WBR1X               DPIH
              INCH                                INCH           FT/SEC              INCH             INCH                 FT                PSI
            .10000          50.00000           3.00000         82.10592            .40819           .28868           25.88858             .51400
             WBREX               TTX             DO1NX               LC              LSCX              LTX               DPLC              WINXX
                FT              INCH              INCH               FT                FT               FT                PSI               INCH
          25.88858            .05787            .21575          7.31723            .38834          7.70557            1.40663            3.00000
             WOUXX                TF             QTOTC             QFTC              QTTC            QTOTS               FEFC                NUE
              INCH              INCH              B/HR             B/HR              B/HR             B/HR                           NO OF G.S
           3.00000         .07534052          121375.8         116426.5            4949.3           4772.2             .89767            1.49806
               NPG                MT                MF              MIF               MIH              MII                MCR                ACR
         NO OF G.S               LBS               LBS              LBS               LBS              LBS                LBS              SQ FT
           9.66707          40.94798         207.77359           .00000           2.69777           .14074          251.56008          199.48624

              DIIN                 N              WINA              VIN             DIINH             D1HA              WBR1X               DPIH
              INCH                                INCH           FT/SEC              INCH             INCH                 FT                PSI
            .10000          50.00000           4.00000         82.10592            .40819           .28868           34.27263             .68253
             WBREX               TTX             DO1NX               LC              LSCX              LTX               DPLC              WINXX
                FT              INCH              INCH               FT                FT               FT                PSI               INCH
```

FIGURE C-4

```
  34.27263       .06436      .22872     6.54970      .34796     6.89766     1.43810     4.00000
     WOUXX           TF       QTOTC        QFTC        QTTC       QTOTS        FEFC         NUE
      INCH         INCH        B/HR        B/HR        B/HR        B/HR               NO OF G.S
   4.00000   .04428121    121375.8    117058.6      4317.2      4772.2      .76406     1.47861
       NPG           MT          MF         MIF         MIH         MLI         MCR         ACR
 NO OF G.S          LBS         LBS         LBS         LBS         LBS         LBS       SQ FT
   9.56520     43.71893   144.71634      .00000     3.57144      .16052   192.16722   256.40098

  DIIN    .10000    N    60.00000    WINA    1.00000    FEFF    1.29897    OUT OF RANGE

      DIIN            K        WINA         VIN       DIINH        D1HA       WBR1X        DPIH
      INCH                     INCH      FT/SEC        INCH        INCH          FT         PSI
    .10000     60.00000     2.00000    68.42160      .44715      .31623    21.41768      .26887
     WBREX          TTX       D01NX          LC        LSCX         LTX        DPLC       WINXX
        FT         INCH        INCH          FT          FT          FT         PSI        INCH
  21.41768       .09263      .28525    11.18164      .53307    11.71472     1.81490     2.00000
     WOUXX           TF       QTOTC        QFTC        QTTC       QTOTS        FEFC         NUE
      INCH         INCH        B/HR        B/HR        B/HR        B/HR               NO OF G.S
   2.00000   .00680132    121375.8    111092.9     10282.9      4772.2      .67543     1.15469
       NPG           MT          MF         MIF         MIH         MLI         MCR         ACR
 NO OF G.S          LBS         LBS         LBS         LBS         LBS         LBS       SQ FT
   8.20409    140.86089    23.59101      .00000     2.42483      .16589   167.04261   250.90209

      DIIN            K        WINA         VIN       DIINH        D1HA       WBR1X        DPIH
      INCH                     INCH      FT/SEC        INCH        INCH          FT         PSI
    .10000     60.00000     3.00000    68.42160      .44715      .31623    31.39625      .40003
     WBREX          TTX       D01NX          LC        LSCX         LTX        DPLC       WINXX
        FT         INCH        INCH          FT          FT          FT         PSI        INCH
  31.39625       .09088      .28176    10.37358      .49167    10.84525     1.68374     3.00000
     WOUXX           TF       QTOTC        QFTC        QTTC       QTOTS        FEFC         NUE
      INCH         INCH        B/HR        B/HR        B/HR        B/HR               NO OF G.S
   3.00000   .00583327    121375.8    111981.4      9394.4      4772.2      .49127     1.14882
       NPG           MT          MF         MIF         MIH         MLI         MCR         ACR
 NO OF G.S          LBS         LBS         LBS         LBS         LBS         LBS       SQ FT
   8.22105    129.20679    27.50923      .00000     3.55457      .18917   160.45976   341.12815

      DIIN            K        WINA         VIN       DIINH        D1HA       WBR1X        DPIH
      INCH                     INCH      FT/SEC        INCH        INCH          FT         PSI
    .10000     60.00000     4.00000    68.42160      .44715      .31623    41.36920      .53119
     WBREX          TTX       D01NX          LC        LSCX         LTX        DPLC       WINXX
        FT         INCH        INCH          FT          FT          FT         PSI        INCH
  41.36920       .08858      .27715     9.56552      .45468    10.02020     1.55259     4.00000
     WOUXX           TF       QTOTC        QFTC        QTTC       QTOTS        FEFC         NUE
      INCH         INCH        B/HR        B/HR        B/HR        B/HR               NO OF G.S
   4.00000   .00645341    121375.8    112858.0      8517.8      4772.2      .40468     1.14195
       NPG           MT          MF         MIF         MIH         MLI         MCR         ACR
 NO OF G.S          LBS         LBS         LBS         LBS         LBS         LBS       SQ FT
```

FIGURE C-4 (cont'd)

8.16107	116.99126	36.98211	.00000	4.68367	.21326	158.87029	414.52774

DIIN	K	WINA	VIN	DIINH	D1HA	WBR1X	DPIH
INCH		INCH	FT/SEC	INCH	INCH	FT	PSI
.10000	70.00000	1.00000	58.64708	.48297	.34157	13.54333	.11141
WBREX	TTX	D01NX	LC	LSCX	LTX	DPLC	WINXX
FT	INCH	INCH	FT	FT	FT	PSI	INCH
13.54333	.11132	.32264	17.13892	.78146	17.92038	1.95013	1.00000
WOUXX	TF	QTOTC	QFTC	QTTC	QTOTS	FEFC	NUE
INCH	INCH	B/HR	B/HR	B/HR	B/HR		NO OF G.S
1.00000	.00168281	121375.8	100825.1	20550.7	4772.2	.67104	.82620
NPG	MT	MF	MIF	MIH	MLI	MCR	ACR
NO OF G.S	LBS	LBS	LBS	LBS	LBS	LBS	SQ FT
6.10546	325.13110	5.64620	.00000	1.64554	.21200	332.63484	242.70165

FIGURE C-4 (cont'd)

DIIN	K	WINA	VIN	DIINH	D1HA	WBR1X	DPIH
INCH		INCH	FT/SEC	INCH	INCH	FT	PSI
.10000	70.00000	2.00000	58.64708	.48297	.34157	25.18563	.21752
WBREX	TTX	D01NX	LC	LSCX	LTX	DPLC	WINXX
FT	INCH	INCH	FT	FT	FT	PSI	INCH
25.18563	.10963	.31926	16.20640	.73064	16.93704	1.84403	2.00000
WOUXX	TF	QTOTC	QFTC	QTTC	QTOTS	FEFC	NUE
INCH	INCH	B/HR	B/HR	B/HR	B/HR		NO OF G.S
2.00000	.00126362	121375.8	102151.3	19224.5	4772.2	.36518	.82412
NPG	MT	MF	MIF	MIH	MLI	MCR	ACR
NO OF G.S	LBS	LBS	LBS	LBS	LBS	LBS	SQ FT
6.16322	303.31131	7.45171	.00000	3.06010	.23712	314.06024	426.57015

DIIN	K	WINA	VIN	DIINH	D1HA	WBR1X	DPIH
INCH		INCH	FT/SEC	INCH	INCH	FT	PSI
.10000	70.00000	3.00000	58.64708	.48297	.34157	36.82529	.32362
WBREX	TTX	D01NX	LC	LSCX	LTX	DPLC	WINXX
FT	INCH	INCH	FT	FT	FT	PSI	INCH
36.82529	.10772	.31543	15.27388	.68855	15.96243	1.73792	3.00000
WOUXX	TF	QTOTC	QFTC	QTTC	QTOTS	FEFC	NUE
INCH	INCH	B/HR	B/HR	B/HR	B/HR		NO OF G.S
3.00000	.00142205	121375.8	103464.0	17911.8	4772.2	.25861	.82178
NPG	MT	MF	MIF	MIH	MLI	MCP	ACR
NO OF G.S	LBS	LBS	LBS	LBS	LBS	LBS	SQ FT
6.15069	281.48752	11.55600	.00000	4.47434	.26413	297.78198	587.82113

DIIN	K	WINA	VIN	DIINH	D1HA	WBR1X	DPIH

INCH		INCH	FT/SEC	INCH	INCH	FT	PSI
.10000	70.00000	4.00000	58.64708	.48297	.34157	48.46371	.42973
WBREX	TTX	DO1NX	LC	LSCX	LTX	DPLC	WINXX
FT	INCH	INCH	FT	FT	FT	PSI	INCH
48.46371	.10569	.31139	14.34136	.64780	14.98916	1.63182	4.00000
WOUXX	TF	QTOTC	QFTC	QTTC	QTOTS	FEFC	NUE
INCH	INCH	B/HR	B/HR	B/HR	B/HR		NO OF G.S
4.00000	.00167242	121375.8	104762.6	16613.2	4772.2	.20966	.81914
NPG	MT	MF	MIF	MIH	MLI	MCR	ACR
NO OF G.S	LBS	LBS	LBS	LBS	LBS	LBS	SQ FT
6.12380	260.12973	16.79527	.00000	5.88843	.29142	283.10484	726.43039

DIIN	K	WINA	VIN	DIINH	D1HA	WBR1X	DPIH
INCH		INCH	FT/SEC	INCH	INCH	FT	PSI
.10000	80.00000	1.00000	51.31620	.51632	.36515	15.65012	.09272
WBREX	TTX	DO1NX	LC	LSCX	LTX	DPLC	WINXX
FT	INCH	INCH	FT	FT	FT	PSI	INCH
15.65012	.12423	.34846	21.65156	.96115	22.61271	1.95440	1.00000
WOUXX	TF	QTOTC	QFTC	QTTC	QTOTS	FEFC	NUE
INCH	INCH	B/HR	B/HR	B/HR	B/HR		NO OF G.S
1.00000	.00042495	121375.8	89628.2	31747.6	4772.2	.40970	.66220
NPG	MT	MF	MIF	MIH	MLI	MCR	ACR
NO OF G.S	LBS	LBS	LBS	LBS	LBS	LBS	SQ FT
5.01316	554.01620	2.07899	.00000	2.02221	.28748	558.40486	353.89152

FIGURE C-4 (cont'd)

DIIN	K	WINA	VIN	DIINH	D1HA	WBR1X	DPIH
INCH		INCH	FT/SEC	INCH	INCH	FT	PSI
.10000	80.00000	2.00000	51.31620	.51632	.36515	28.95579	.18103
WBREX	TTX	DO1NX	LC	LSCX	LTX	DPLC	WINXX
FT	INCH	INCH	FT	FT	FT	PSI	INCH
28.95579	.12255	.34511	20.67325	.91482	21.58807	1.86609	2.00000
WOUXX	TF	QTOTC	QFTC	QTTC	QTOTS	FEFC	NUE
INCH	INCH	B/HR	B/HR	B/HR	B/HR		NO OF G.S
2.00000	.00045798	121375.8	91327.4	30048.4	4772.2	.21888	.66117
NPG	MT	MF	MIF	MIH	MLI	MCR	ACR
NO OF G.S	LBS	LBS	LBS	LBS	LBS	LBS	SQ FT
5.02315	522.04987	3.95769	.00000	3.74148	.31730	530.06633	625.09969

DIIN	K	WINA	VIN	DIINH	D1HA	WBR1X	DPIH
INCH		INCH	FT/SEC	INCH	INCH	FT	PSI
.10000	80.00000	3.00000	51.31620	.51632	.36515	42.26058	.26934
WBREX	TTX	DO1NX	LC	LSCX	LTX	DPLC	WINXX
FT	INCH	INCH	FT	FT	FT	PSI	INCH
47.26058	.12081	.34162	19.69494	.87152	20.56645	1.77778	3.00000
WOUXX	TF	QTOTC	QFTC	QTTC	QTOTS	FEFC	NUE
INCH	INCH	B/HR	B/HR	B/HR	B/HR		NO OF G.S

3.00000	.00054335	121375.8	93012.1	28363.7	4772.2	.15620	.66003
NPG	MT	MF	MIF	MIH	MLI	MCR	ACR
NO OF G.S	LBS	LBS	LBS	LBS	LBS	LBS	SQ FT
5.01677	490.70718	6.52865	.00000	5.46064	.34787	503.04433	839.15027

DIIN	N	WINA	VIN	DIINH	D1HA	WBR1X	DPIH
INCH		INCH	FT/SEC	INCH	INCH	FT	PSI
.10000	80.00000	4.00000	51.31620	.51632	.36515	55.56449	.35765
WBREX	TTX	DO1NX	LC	LSCX	LTX	DPLC	WINXX
FT	INCH	INCH	FT	FT	FT	PSI	INCH
55.56449	.11900	.33801	18.71663	.82863	19.54526	1.68947	4.00000
WOUXX	TF	QTOTC	QFTC	QTTC	QTOTS	FEFC	NUE
INCH	INCH	B/HR	B/HR	B/HR	B/HR		NO OF G.S
4.00000	.00064868	121375.8	94681.7	26694.1	4772.2	.12567	.65877
NPG	MT	MF	MIF	MIH	MLI	MCR	ACR
NO OF G.S	LBS	LBS	LBS	LBS	LBS	LBS	SQ FT
5.00718	459.98117	9.73911	.00000	7.17968	.37854	477.27850	1086.02230

DIIN	N	WINA	VIN	DIINH	D1HA	WBR1X	DPIH
INCH		INCH	FT/SEC	INCH	INCH	FT	PSI
.12000	50.00000	1.00000	57.01800	.48982	.34641	9.74266	.07514
WBREX	TTX	DO1NX	LC	LSCX	LTX	DPLC	WINXX
FT	INCH	INCH	FT	FT	FT	PSI	INCH
9.74266	.10959	.33917	21.11191	.97825	22.09016	1.98304	1.00000
WOUXX	TF	QTOTC	QFTC	QTTC	QTOTS	FEFC	NUE
INCH	INCH	B/HR	B/HR	B/HR	B/HR		NO OF G.S
1.00000	.00300504	121375.8	101813.9	19561.9	4772.2	.77008	.68414
NPG	MT	MF	MIF	MIH	MLI	MCR	ACR
NO OF G.S	LBS	LBS	LBS	LBS	LBS	LBS	SQ FT
4.97093	305.57510	8.94079	.00000	1.19919	.26239	315.97745	215.21696

DIIN	N	WINA	VIN	DIINH	D1HA	WBR1X	DPIH
INCH		INCH	FT/SEC	INCH	INCH	FT	PSI
.12000	50.00000	2.00000	57.01800	.48982	.34641	1[illegible].06623	.14602
WBREX	TTX	DO1NX	LC	LSCX	LTX	DPLC	WINXX
FT	INCH	INCH	FT	FT	FT	PSI	INCH
18.06623	.10882	.33763	20.35725	.92680	21.28405	1.91215	2.00000
WOUXX	TF	QTOTC	QFTC	QTTC	QTOTS	FEFC	NUE
INCH	INCH	B/HR	B/HR	B/HR	B/HR		NO OF G.S
2.00000	.00162731	121375.8	102637.9	18737.9	4772.2	.40304	.68311
NPG	MT	MF	MIF	MIH	MLI	MCR	ACR
NO OF G.S	LBS	LBS	LBS	LBS	LBS	LBS	SQ FT
5.05367	293.72283	8.65048	.00000	2.22370	.28811	3[illegible]8511	384.52253

FIGURE C-4 (cont'd)

DIIN	N	WINA	VIN	DIINH	D1HA	WBR1X	DPIH
INCH		INCH	FT/SEC	INCH	INCH	FT	PSI
.12000	50.00000	3.00000	57.01800	.48982	.34641	26.38624	.21691
WBREX	TTX	D01NX	LC	LSCX	LTX	DPLC	WINXX
FT	INCH	INCH	FT	FT	FT	PSI	INCH
26.38624	.10762	.33523	19.60259	.89070	20.49329	1.84127	3.00000
WOUXX	TF	QTOTC	QFTC	QTTC	QTOTS	FEFC	NUE
INCH	INCH	B/HR	B/HR	B/HR	B/HR		NO OF G.S
3.00000	.00169099	121375.8	103456.9	17918.9	4772.2	.28164	.68200
NPG	MT	MF	MIF	MIH	MLI	MCR	ACR
NO OF G.S	LBS	LBS	LBS	LBS	LBS	LBS	SQ FT
5.05741	280.62952	12.64097	.00000	3.24778	.31726	296.83551	540.74106

DIIN	N	WINA	VIN	DIINH	D1HA	WBR1X	DPIH
INCH		INCH	FT/SEC	INCH	INCH	FT	PSI
.12000	50.00000	4.00000	57.01800	.48982	.34641	34.70575	.28779
WBREX	TTX	D01NX	LC	LSCX	LTX	DPLC	WINXX
FT	INCH	INCH	FT	FT	FT	PSI	INCH
34.70575	.10636	.33271	18.84793	.85696	19.70489	1.77038	4.00000
WOUXX	TF	QTOTC	QFTC	QTTC	QTOTS	FEFC	NUE
INCH	INCH	B/HR	B/HR	B/HR	B/HR		NO OF G.S
4.00000	.00186657	121375.8	104270.6	17105.2	4772.2	.22173	.68080
NPG	MT	MF	MIF	MIH	MLI	MCR	ACR
NO OF G.S	LBS	LBS	LBS	LBS	LBS	LBS	SQ FT
5.04758	267.64616	17.64692	.00000	4.27180	.34693	289.91179	683.87289

FIGURE C-4 (cont'd)

DIIN	N	WINA	VIN	DIINH	D1HA	WBR1X	DPIH
INCH		INCH	FT/SEC	INCH	INCH	FT	PSI
.12000	60.00000	1.00000	47.51500	.53658	.37947	11.90161	.05848
WBREX	TTX	D01NX	LC	LSCX	LTX	DPLC	WINXX
FT	INCH	INCH	FT	FT	FT	PSI	INCH
11.90161	.13064	.38127	31.61268	1.40110	33.01378	1.98192	1.00000
WOUXX	TF	QTOTC	QFTC	QTTC	QTOTS	FEFC	NUE
INCH	INCH	B/HR	B/HR	B/HR	B/HR		NO OF G.S
1.00000	.00028539	121375.8	82416.5	38959.3	4772.2	.34237	.46228
NPG	MT	MF	MIF	MIH	MLI	MCR	ACR
NO OF G.S	LBS	LBS	LBS	LBS	LBS	LBS	SQ FT
3.50074	711.19069	1.55018	.00000	1.59360	.42930	714.76376	392.91704

DIIN	N	WINA	VIN	DIINH	D1HA	WBR1X	DPIH
INCH		INCH	FT/SEC	INCH	INCH	FT	PSI
.12000	60.00000	2.00000	47.51500	.53658	.37947	21.88687	.11364
WBREX	TTX	D01NX	LC	LSCX	LTX	DPLC	WINXX
FT	INCH	INCH	FT	FT	FT	PSI	INCH

21.88687	.12956	.37913	30.73273	1.35880	32.09153	1.92675	2.00000
WOUXX	TF	QTOTC	QFTC	QTTC	QTOTS	FEFC	NUE
INCH	INCH	B/HR	B/HR	B/HR	B/HR		NO OF G,S
2.00000	.00031242	121375.8	83691.4	37684.4	4772.2	.17892	.46192
NPG	MT	MF	MIF	MIH	MLI	MCR	ACR
NO OF G,S	LBS	LBS	LBS	LBS	LBS	LBS	SQ FT
3.50716	686.33565	3.03358	.00000	2.93060	.46261	692.76243	702.38312

DIIN	N	WINA	VIN	DIINH	D1HA	WBR1X	DPIH
INCH		INCH	FT/SEC	INCH	INCH	FT	PSI
.12000	60.00000	3.00000	47.51500	.53658	.37947	31.87187	.16881
WBREX	TTX	DO1NX	LC	LSCX	LTX	DPLC	WINXX
FT	INCH	INCH	FT	FT	FT	PSI	INCH
31.87187	.12846	.37693	29.85279	1.31898	31.17176	1.87159	3.00000
WOUXX	TF	QTOTC	QFTC	QTTC	QTOTS	FEFC	NUE
INCH	INCH	B/HR	B/HR	B/HR	B/HR		NO OF G,S
3.00000	.00036154	121375.8	84960.0	36415.8	4772.2	.12473	.46152
NPG	MT	MF	MIF	MIH	MLI	MCR	ACR
NO OF G,S	LBS	LBS	LBS	LBS	LBS	LBS	SQ FT
3.50739	661.78532	4.96564	.00000	4.26757	.49659	671.51511	993.50255

DIIN	N	WINA	VIN	DIINH	D1HA	WBR1X	DPIH
INCH		INCH	FT/SEC	INCH	INCH	FT	PSI
.12000	60.00000	4.00000	47.51500	.53658	.37947	41.85664	.22398
WBREX	TTX	DO1NX	LC	LSCX	LTX	DPLC	WINXX
FT	INCH	INCH	FT	FT	FT	PST	INCH
41.85664	.12734	.37468	28.97284	1.27950	30.25235	1.81642	4.00000
WOUXX	TF	QTOTC	QFTC	QTTC	QTOTS	FEFC	NUE
INCH	INCH	B/HR	B/HR	B/HR	P/HR		NO OF G,S
4.00000	.00041839	121375.8	86222.1	35153.7	4772.2	.09789	.46111
NPG	MT	MF	MIF	MIH	MLI	MCR	ACR
NO OF G,S	LBS	LBS	LBS	LBS	LBS	LBS	SQ FT
3.50666	637.51528	7.32408	.00000	5.60451	.53066	650.97452	1266.26150

DIIN	N	WINA	VIN	DIINH	D1HA	WBR1X	DPIH
INCH		INCH	FT/SEC	INCH	INCH	FT	PSI
.12000	70.00000	1.00000	40.72714	.57957	.40988	14.08373	.04731
WBREX	TTX	DO1NX	LC	LSCX	LTX	DPLC	WINXX
FT	INCH	INCH	FT	FT	FT	PSI	INCH
14.08373	.14766	.41532	41.27173	1.81425	43.08597	1.98237	1.00000
WOUXX	TF	QTOTC	QFTC	QTTC	QTOTS	FEFC	NUE
INCH	INCH	B/HR	B/HR	B/HR	B/HR		NO OF G,S
1.00000	.00006057	121375.8	57511.4	63864.4	4772.2	.15592	.35679
NPG	MT	MF	MIF	MIH	MLI	MCR	ACR
NO OF G,S	LBS	LBS	LBS	LBS	LBS	LBS	SQ FT
2.71910	1305.35870	.50815	.00000	2.02581	.63111	1308.52380	606.81119

FIGURE C-4 (cont'd)

DIIN	N	WINA	VIN	DIINH	D1HA	WBR1X	DPIH
INCH		INCH	FT/SEC	INCH	INCH	FT	PSI
.12000	70.00000	2.00000	40.72714	.57957	.40988	25.73427	.09194
WBREX	TTX	DO1NX	LC	LSCX	LTX	DPLC	WINXX
FT	INCH	INCH	FT	FT	FT	PSI	INCH
25.73427	.14668	.41336	40.34255	1.77025	42.11280	1.93774	2.00000
WOUXX	TF	QTOTC	QFTC	QTTC	QTOTS	FEFC	NUE
INCH	INCH	B/HR	B/HR	B/HR	B/HR		NO OF G,S
2.00000	.00007767	121375.8	59203.2	62172.6	4772.2	.08213	.35662
NPG	MT	MF	MIF	MIH	MLI	MCR	ACR
NO OF G,S	LBS	LBS	LBS	LBS	LBS	LBS	SQ FT
2.72299	1267.83810	1.16372	.00000	3.70162	.66944	1273.37280	1083.74230

DIIN	N	WINA	VIN	DIINH	D1HA	WBR1X	DPIH
INCH		INCH	FT/SEC	INCH	INCH	FT	PSI
.12000	70.00000	3.00000	40.72714	.57957	.40988	37.38463	.13697
WBREX	TTX	DO1NX	LC	LSCX	LTX	DPLC	WINXX
FT	INCH	INCH	FT	FT	FT	PSI	INCH
37.38463	.14568	.41136	39.41338	1.72702	41.14040	1.89311	3.00000
WOUXX	TF	QTOTC	QFTC	QTTC	QTOTS	FEFC	NUE
INCH	INCH	B/HR	B/HR	B/HR	B/HR		NO OF G,S
3.00000	.00009783	121375.8	60888.2	60487.6	4772.2	.05766	.35645
NPG	MT	MF	MIF	MIH	MLI	MCR	ACR
NO OF G,S	LBS	LBS	LBS	LBS	LBS	LBS	SQ FT
2.72586	1230.69250	2.08009	.00000	5.37741	.70803	1238.45800	1538.01870

DIIN	N	WINA	VIN	DIINH	D1HA	WBR1X	DPIH
INCH		INCH	FT/SEC	INCH	INCH	FT	PSI
.12000	70.00000	4.00000	40.72714	.57957	.40988	49.03479	.18120
WBREX	TTX	DO1NX	LC	LSCX	LTX	DPLC	WINXX
FT	INCH	INCH	FT	FT	FT	PSI	INCH
49.03479	.14466	.40933	38.48421	1.68452	40.16873	1.84848	4.00000
WOUXX	TF	QTOTC	QFTC	QTTC	QTOTS	FEFC	NUE
INCH	INCH	B/HR	B/HR	B/HR	B/HR		NO OF G,S
4.00000	.00012048	121375.8	62556.0	58809.7	4772.2	.04553	.35627
NPG	MT	MF	MIF	MIH	MLI	MCR	ACR
NO OF G,S	LBS	LBS	LBS	LBS	LBS	LBS	SQ FT
2.72770	1193.92540	3.28071	.00000	7.05317	.74683	1205.00610	1969.66550

DIIN	N	WINA	VIN	DIINH	D1HA	WBR1X	DPIH
INCH		INCH	FT/SEC	INCH	INCH	FT	PSI

FIGURE C-4 (cont'd)

.12000	80.00000	1.00000	35.63625	.61958	.43818	16.31485	.03957
WBREX	TTX	DOINX	LC	LSCX	LTX	DPLC	WINXX
FT	INCH	INCH	FT	FT	FT	PSI	INCH
16.31485	.16410	.44821	51.85647	2.28722	54.13870	1.98335	1.00000
WOUXX	TF	GTOTC	GFTC	GTTC	GTOTS	FEFC	NUE
INCH	INCH	B/HR	B/HR	B/HR	B/HR		NO OF G.S
1.00000	.00000725	121375.8	23619.5	97756.3	4772.2	.04442	.28546
NPG	MT	MF	MIF	MIH	MLI	MCR	ACR
NO OF G.S	LBS	LBS	LBS	LBS	LBS	LBS	SQ FT
2.17032	2209.28900	.08851	.00000	2.49771	.88972	2212.76490	883.26492

DIIN	N	WINA	VIN	DIINH	D1HA	WBR1X	DPIH
INCH		INCH	FT/SEC	INCH	INCH	FT	PSI
.12000	80.00000	2.00000	35.63625	.61958	.43818	29.63076	.07652
WBREX	TTX	DOINX	LC	LSCX	LTX	DPLC	WINXX
FT	INCH	INCH	FT	FT	FT	PSI	INCH
29.63076	.16320	.44639	50.88531	2.23639	53.12169	1.94621	2.00000
WOUXX	TF	GTOTC	GFTC	GTTC	GTOTS	FEFC	NUE
INCH	INCH	B/HR	B/HR	B/HR	B/HR		NO OF G.S
2.00000	.00001252	121375.8	25777.2	95598.6	4772.2	.02471	.28537
NPG	MT	MF	MIF	MIH	MLI	MCR	ACR
NO OF G.S	LBS	LBS	LBS	LBS	LBS	LBS	SQ FT
2.17285	2155.77390	.27249	.00000	4.53630	.93288	2161.51550	1574.03600

FIGURE C-4 (cont'd)

DIIN	N	WINA	VIN	DIINH	D1HA	WBR1X	DPIH
INCH		INCH	FT/SEC	INCH	INCH	FT	PSI
.12000	80.00000	3.00000	35.63625	.61958	.43818	42.94663	.11366
WBREX	TTX	DOINX	LC	LSCX	LTX	DPLC	WINXX
FT	INCH	INCH	FT	FT	FT	PSI	INCH
42.94663	.16229	.44457	49.91414	2.20308	52.11722	1.90908	3.00000
WOUXX	TF	GTOTC	GFTC	GTTC	GTOTS	FEFC	NUE
INCH	INCH	B/HR	B/HR	B/HR	B/HR		NO OF G.S
3.00000	.00001825	121375.8	27927.4	93448.4	4772.2	.01820	.28529
NPG	MT	MF	MIF	MIH	MLI	MCR	ACR
NO OF G.S	LBS	LBS	LBS	LBS	LBS	LBS	SQ FT
2.16310	2103.38560	.56460	.00000	6.57488	.98053	2111.50560	7238.25900

DIIN	N	WINA	VIN	DIINH	D1HA	WBR1X	DPIH
INCH		INCH	FT/SEC	INCH	INCH	FT	PSI
.12000	80.00000	4.00000	35.63625	.61958	.43818	56.26209	.15080
WBREX	TTX	DOINX	LC	LSCX	LTX	DPLC	WINXX
FT	INCH	INCH	FT	FT	FT	PSI	INCH
56.26209	.16135	.44269	48.94298	2.14720	51.09018	1.87192	4.00000
WOUXX	TF	GTOTC	GFTC	GTTC	GTOTS	FEFC	NUE
INCH	INCH	B/HR	B/HR	B/HR	B/HR		NO OF G.S
4.00000	.00002610	121375.8	30070.1	91305.7	4772.2	.01499	.28520

NPG	MT	MF	MIF	MIH	MLI	MCR	ACR
NO OF G,S	LBS	LBS	LBS	LBS	LBS	LBS	SQ FT
2.17569	2050.15640	1.03720	.00000	8.61340	1.02010	2060.82710	9874.44010

FIGURE C-4 (cont'd)

SAMPLE INPUT DATA SHEET - PRIMARY/SECONDARY DESIGN PROGRAM

FORTRAN DATA SHEET

COLS	1 - 10	11 - 20	21 - 30	31 - 40	41 - 50	51 - 60	61 - 70	71 - 80
1	SAMPLE CA	SE NØ 3, Ø	PEN SANDWI	CH FLAT PL	ATE RADIAT	ØR. WØRKIN	G FLUID-ME	RCURY
	Nº OF TS's							
2	02							
	TS							
3	0.0							
	TS							
4	400.							
	PC	TC	MDT	XIN	DPTOT	TOUT	R	GAMMA
5	6.6	1060.	13.7	1.0	3.0	860.	7.74	1.656
	VISV	VISL	HFG	CL	RHOL	SVFT	KC	RHOT
6	.0000356	.00059	127.	.0326	820.	.0326	8.	500.
	RHOF	KTH	KF	RHOH	TH	FSV	ET	EF
7	166.	10.7	125.	500.	.05	.8	.85	.85
	CV	TIN	TAU	-LNPO	MEF	METH	TTG	NVEG
8	.0249	1070.	400.	.0513	10000000.	30000000.		
	TFMIN	TFMAX	LPMIN	LPMAX	WMIN	WMAX	TIF	RHIF
9	0.0							
	LTMAX	ALPHS	ALPHT	DIINP O	DIINP F	DIINP D	N O	N F
10				.50	.52	.02	10.	14.
	N D	WINA O	WINA F	WINA D				
11	2.	5.	6.	1.0				
	PUNT							
12	2121							

Z-000 PRINTED IN U.S.A.

TITLE	ENGR.	PROJECT
SAMPLE INPUT SHEET	DATE	JOB NO.
DESIGN PROGRAM, ISOTHERMAL		
PRIM/SEC DIRECT R/C w/SC	PAGE 1 OF 1 PAGES	

EDP SERVICES

Figure C-5

SAMPLE OUTPUT
PRIMARY/SECONDARY DESIGN PROGRAM

SAMPLE CASE NO. 3. OPEN SANDWICH FLAT PLATE RADIATOR, WORKING FLUID-MERCURY

PUNT IS 2121

DESIGN PROGRAM ISO-PRIM/SEC DIRECT R/C W/SC

FIXED INPUT

PC	TC	MDT	XIN	DPTOT	TOUT	R	GAMMA
PSIA	DEG R	LBS/MIN		PSI	DEG R	FT/R	
6.60000	1060.00000	13.70000	1.00000	3.00000	860.00000	7.74000	1.65600
VISV	VISL	HFG	CL	RHOL	SUFT	KC	RHOT
LBS/FT SEC	LBS/FT SEC	B/LB	B/LB F	LBS/CU.FT	LBS/FT	B/HR FT F	LBS/CU.FT
.000035600	.000590000	127.00000	.03260	820.00000	.03260	8.00000	500.00000
RHOF	KTH	KF	RHOH	TH	FSV	ET	EF
LBS/CU.FT	B/HR FT F	B/HR FT F	LBS/CU.FT	INCH			
165.99999	10.70000	125.00000	500.00000	.05000	.80000	.85000	.85000
CV	TIN	TAU	-LNPO	MEF	METH	TTG	NUFG
B/LBS F	DEG R	DAYS		PSI	PSI	INCH	NO OF 6.S
.024900	1069.999900	400.000000	.051300	10000000.00	30000000.00	-.000000	-.000000
TFMIN	TFMAX	LPMIN	LPMAX	WMIN	WMAX	TIF	RHIF
INCH	INCH	FT	FT	FT	FT	INCH	LBS/CU.FT
.00000	.50000	-.00000	-.00000	-.00000	-.00000	-.00000	-.00000
LTMAX	ALPHS	ALPHT	DIINP O	DIINP F	DIINP D	N O	N F
FT			INCH	INCH	INCH		
.00000	-.00000	-.00000	.50000	.52000	.02000	10.00000	14.00000
N D	WINA O	WINA F	WINA D				
	INCH	INCH	INCH				
2.00000	5.00000	6.00000	1.00000				

PPWR IS .00021238

TS IS .0 DEG R

DIINP	.50000	N	10.00000	WINA	5.00000	FEFF	1.09194	OUT OF RANGE
DIINP	.50000	N	10.00000	WINA	6.00000	TFP	-.48595	OUT OF RANGE

DIINP	N	WINA	VIN	DIINH	WBRIX	DPIH	DIEHE
INCH		INCH	FT/SEC	INCH	FT	PSI	INCH
.50000	12.00000	5.00000	120.63161	1.72456	10.45930	.16027	.61228
DPEH	TTP	LCP	DPLCP	DIEP	FEFP	TFP	DIINS
PSI	INCH	FT	PSI	INCH		INCH	INCH
.53913	.04236	4.09535	1.54966	.17700	.64724	.10638	.86603
LCS	DPLCS	LSCS	LT	TFS	WINS	DISC	QTOTP
FT	PSI	FT	FT	INCH	INCH	INCH	B/HR
3.52516	.77483	7.23169	9.85219	.38933	11.72203	.10108	91549.47600
QTOTS	QSC	MT	MF	MIF	MHS	MLI	MCR
B/HR	B/HR	LBS	LBS	LBS	LBS	LBS	LBS

FIGURE C-6

13049.24980	5359.43980	10.74348	125.42346	.00000	7.97496	.10190	144.24379
ACRP	ACRS	NUE					
SQ FT	SQ FT	NO OF G,S					
42.83446	11.59458	.70470					
DIINP	K	WINA	VIN	DIINH	WRRIX	DPIH	DIEHE
INCH		INCH	FT/SEC	INCH	FT	PSI	INCH
.50000	12.00000	6.00000	120.63161	1.22456	12.45768	.19116	.61228
DPEH	TTP	LCP	DPLCP	DIEP	FEFP	TFP	DIINS
PSI	INCH	FT	PSI	INCH		INCH	INCH
.64306	.04159	3.85769	1.45973	.17700	.58149	.10546	.86603
LCS	DPLCS	LSCS	LT	TFS	WINS	DISC	QTOTP
FT	PSI	FT	FT	INCH	INCH	INCH	B/HR
3.32059	.72986	2.10218	9.28047	.44816	12.67693	.10108	91549.42600
QTOTS	QSC	MT	MF	MIF	MHS	MLI	MCR
B/HR	B/HR	LBS	LBS	LBS	LBS	LBS	LBS
13049.24980	5359.43980	9.91833	142.81887	.00000	9.49868	.09598	162.33186
ACRP	ACRS	NUE					
SQ FT	SQ FT	NO OF G,S					
48.05790	11.73857	.73666					
DIINP	K	WINA	VIN	DIINH	WRRIX	DPIH	DIEHE
INCH		INCH	FT/SEC	INCH	FT	PSI	INCH
.50000	14.00000	5.00000	103.39852	1.32268	12.24918	.12966	.66134
DPEH	TTP	LCP	DPLCP	DIEP	FEFP	TFP	DIINS
PSI	INCH	FT	PSI	INCH		INCH	INCH
.43615	.06236	5.65723	1.63474	.17700	.35262	.02157	.93541
LCS	DPLCS	LSCS	LT	TFS	WINS	DISC	QTOTP
FT	PSI	FT	FT	INCH	INCH	INCH	B/HR
5.36278	.81737	3.39504	14.41504	.14143	6.87422	.10108	91549.42600
QTOTS	QSC	MT	MF	MIF	MHS	MLI	MCR
B/HR	B/HR	LBS	LBS	LBS	LBS	LBS	LBS
13049.24980	5359.43980	26.70548	41.46519	.00000	10.03454	.15502	78.36023
ACRP	ACRS	NUE					
SQ FT	SQ FT	NO OF G,S					
69.29640	10.63263	.43993					
DIINP	K	WINA	VIN	DIINH	WRRIX	DPIH	DIEHE
INCH		INCH	FT/SEC	INCH	FT	PSI	INCH
.50000	14.00000	6.00000	103.39852	1.32268	14.57998	.15465	.66134
DPEH	TTP	LCP	DPLCP	DIEP	FEFP	TFP	DIINS
PSI	INCH	FT	PSI	INCH		INCH	INCH
.52023	.06131	5.40547	1.56199	.17700	.31161	.02338	.93541
LCS	DPLCS	LSCS	LT	TFS	WINS	DISC	QTOTP
FT	PSI	FT	FT	INCH	INCH	INCH	B/HR
5.12412	.78099	3.24395	13.77353	.15757	7.27007	.10108	91549.42600

FIGURE C-6 (cont'd)

QTOTS	QSC	MT	MF	MIF	MHS	MLI	MCR
B/HR	B/HR	LBS	LBS	LBS	LBS	LBS	LBS
13049.24980	5359.43980	25.03051	48.81752	.00000	11.94393	.14812	85.94008
ACRP	ACRS	NUE					
SQ FT	SQ FT	NO OF G.S					
78.81155	10.70985	.45346					

DIINP .52000 N 10.00000 WINA 5.00000 PRIMARY-COND. EQUATIONS NONCONVERGENT AFTER 20 TRIES
DIINP .52000 N 10.00000 WINA 6.00000 TFP .81459 OUT OF RANGE

DIINP	N	WINA	VIN	DIINH	WBRIX	DPIH	DIEHE
INCH		INCH	FT/SEC	INCH	FT	PSI	INCH
.52000	12.00000	5.00000	111.53071	1.27354	10.50069	.13322	.63677
DPEH	TTP	LCP	DPLCP	DIEP	FEFP	TFP	DIINS
PSI	INCH	FT	PSI	INCH		INCH	INCH
.44814	.05555	5.17751	1.62619	.18408	.47727	.04391	.90067
LCS	DPLCS	LSCS	LT	TFS	WINS	DISC	QTOTP
FT	PSI	FT	FT	INCH	INCH	INCH	B/HR
4.45679	.81309	2.82148	12.45378	.22153	8.70844	.10108	91549.47600
QTOTS	QSC	MT	MF	MIF	MHS	MLI	MCR
B/HR	B/HR	LBS	LBS	LBS	LBS	LBS	LBS
13049.24980	5359.43980	19.00286	66.81508	.00000	8.30389	.12883	94.25064
ACRP	ACRS	NUE					
SQ FT	SQ FT	NO OF G.S					
54.36737	11.03641	.53227					

FIGURE C-6 (cont'd)

DIINP	N	WINA	VIN	DIINH	WBRIX	DPIH	DIEHE
INCH		INCH	FT/SEC	INCH	FT	PSI	INCH
.52000	12.00000	6.00000	111.53071	1.27354	12.49854	.15886	.63677
DPEH	TTP	LCP	DPLCP	DIEP	FEFP	TFP	DIINS
PSI	INCH	FT	PSI	INCH		INCH	INCH
.53440	.05452	4.93986	1.55155	.18408	.42207	.04580	.90067
LCS	DPLCS	LSCS	LT	TFS	WINS	DISC	QTOTP
FT	PSI	FT	FT	INCH	INCH	INCH	B/HR
4.25223	.77577	2.69198	11.88406	.24740	9.27632	.10108	91549.47600
QTOTS	QSC	MT	MF	MIF	MHS	MLI	MCR
B/HR	B/HR	LBS	LBS	LBS	LBS	LBS	LBS
13049.24980	5359.43980	17.75227	77.16420	.00000	9.88378	.12291	104.92316
ACRP	ACRS	NUE					
SQ FT	SQ FT	NO OF G.S					
61.74102	11.12778	.55000					

DIINP	N	WINA	VIN	DIINH	WBRIX	DPIH	DIEHE
INCH		INCH	FT/SEC	INCH	FT	PSI	INCH
.52000	14.00000	5.00000	95.59775	1.37558	12.28072	.10777	.68779
DPEH	TTP	LCP	DPLCP	DIEP	FEFP	TFP	DIINS
PSI	INCH	FT	PSI	INCH		INCH	INCH

.36254	.06837	7.07431	1.69682	.18408	.25962	.01143	.97283
LCS	DPLCS	LSCS	LT	TFS	WINS	DISC	QTOTP
FT	PSI	FT	FT	INCH	INCH	INCH	B/HR
6.70633	.84841	4.24560	18.02624	.08143	5.16909	.10108	91549.42600
QTOTS	GSC	MT	MF	MIF	MHS	MLI	MCR
B/HR	B/HR	LBS	LBS	LBS	LBS	LBS	LBS
13049.24980	5359.43980	38.35891	25.24354	.00000	10.43602	.19385	74.23232
ACRP	ACRS	NUE					
SQ FT	SQ FT	NO OF G,S					
86.87756	10.22187	.33995					

DIINP	N	WINA	VIN	DIINH	WBRIX	DPIH	DIEHE
INCH		INCH	FT/SEC	INCH	FT	PSI	INCH
.52000	14.00000	6.00000	95.59775	1.37558	14.61207	.12852	.68779
DPEH	TTP	LCP	DPLCP	DIEP	FEFP	TFP	DIINS
PSI	INCH	FT	PSI	INCH		INCH	INCH
.43233	.06756	6.82255	1.63643	.18408	.22713	.01241	.97283
LCS	DPLCS	LSCS	LT	TFS	WINS	DISC	QTOTP
FT	PSI	FT	FT	INCH	INCH	INCH	B/HR
6.46767	.81821	4.09451	17.38473	.08894	5.40842	.10108	91549.42600
QTOTS	GSC	MT	MF	MIF	MHS	MLI	MCR
B/HR	B/HR	LBS	LBS	LBS	LBS	LBS	LBS
13049.24980	5359.43980	36.49213	29.74681	.00000	12.41718	.18695	78.84307
ACRP	ACRS	NUE					
SQ FT	SQ FT	NO OF G,S					
99.69157	10.27782	.34766					

FIGURE C-6 (cont'd)

TS IS 400.0 DEG R

DIINP	.50000	N	10.00000	WINA	5.00000	FEFF	1.11454	OUT OF RANGE	
DIINP	.50000	N	10.00000	WINA	6.00000	FEFF	1.01084	OUT OF RANGE	

DIINP	N	WINA	VIN	DIINH	WBRIX	DPIH	DIEHE
INCH		INCH	FT/SEC	INCH	FT	PSI	INCH
.50000	12.00000	5.00000	120.63161	1.22456	10.45604	.16027	.61228
DPEH	TTP	LCP	DPLCP	DIEP	FEFP	TFP	DIINS
PSI	INCH	FT	PSI	INCH		INCH	INCH
.53913	.04073	4.09535	1.54966	.17700	.66313	.11768	.86603
LCS	DPLCS	LSCS	LT	TFS	WINS	DISC	QTOTP
FT	PSI	FT	FT	INCH	INCH	INCH	B/HR
3.52516	.77483	2.23169	9.85219	.41325	12.03364	.10108	91549.42600
QTOTS	GSC	MT	MF	MIF	MHS	MLI	MCR
B/HR	B/HR	LBS	LBS	LBS	LBS	LBS	LBS
13049.24980	5359.43980	10.29040	137.62648	.00000	7.97247	.10190	155.99125
ACRP	ACRS	NUE					
SQ FT	SQ FT	NO OF G,S					
42.82111	11.89188	.70470					

DIINP	N	WINA	VIN	DIINH	WBRIX	DPIH	DIEHE
INCH		INCH	FT/SEC	INCH	FT	PSI	INCH
.50000	12.00000	6.00000	120.63161	1.22456	12.45484	.19116	.61228
DPEH	TTP	LCP	DPLCP	DIEP	FEFP	TFP	DIINS
PSI	INCH	FT	PSI	INCH		INCH	INCH
.64306	.04017	3.85769	1.45973	.17700	.59590	.11529	.86603
LCS	DPLCS	LSCS	LT	TFS	WINS	DISC	QTOTP
FT	PSI	FT	FT	INCH	INCH	INCH	B/HR
3.32059	.72986	2.10218	9.28047	.47591	12.96489	.10108	91549.42600
QTOTS	QSC	MT	MF	MTF	MHS	MLT	MCR
B/HR	B/HR	LBS	LBS	LBS	LBS	LBS	LBS
13049.24980	5359.43980	9.54782	155.84342	.00000	9.49651	.09598	174.98374
ACRP	ACRS	NUE					
SQ FT	SQ FT	NO OF G.S					
48.04696	12.04261	.73666					

FIGURE C-6 (cont'd)

DIINP	N	WINA	VIN	DIINH	WBRIX	DPIH	DIEHE
INCH		INCH	FT/SEC	INCH	FT	PSI	INCH
.50000	14.00000	5.00000	103.39852	1.32268	12.24863	.12966	.66134
DPEH	TTP	LCP	DPLCP	DIEP	FEFP	TFP	DIINS
PSI	INCH	FT	PSI	INCH		INCH	INCH
.43615	.06212	5.65723	1.63474	.17700	.36079	.02320	.93541
LCS	DPLCS	LSCS	LT	TFS	WINS	DISC	QTOTP
FT	PSI	FT	FT	INCH	INCH	INCH	B/HR
5.36278	.81737	3.39504	14.41504	.14983	7.05224	.10108	91549.42600
QTOTS	QSC	MT	MF	MTF	MHS	MLT	MCR
B/HR	B/HR	LBS	LBS	LBS	LBS	LBS	LBS
13049.24980	5359.43980	26.59079	44.79791	.00000	10.03489	.15502	81.57780
ACRP	ACRS	NUE					
SQ FT	SQ FT	NO OF G.S					
69.29330	10.89203	.43993					

DIINP	N	WINA	VIN	DIINH	WBRIX	DPIH	DIEHE
INCH		INCH	FT/SEC	INCH	FT	PSI	INCH
.50000	14.00000	6.00000	103.39852	1.32268	14.57939	.15465	.66134
DPEH	TTP	LCP	DPLCP	DIEP	FEFP	TFP	DIINS
PSI	INCH	FT	PSI	INCH		INCH	INCH
.52023	.06106	5.40547	1.56199	.17700	.31876	.02514	.93541
LCS	DPLCS	LSCS	LT	TFS	WINS	DISC	QTOTP
FT	PSI	FT	FT	INCH	INCH	INCH	B/HR
5.12412	.78099	3.24395	13.77353	.16693	7.45833	.10108	91549.42600
QTOTS	QSC	MT	MF	MTF	MHS	MLT	MCR
B/HR	B/HR	LBS	LBS	LBS	LBS	LBS	LBS
13049.24980	5359.43980	24.91328	52.71557	.00000	11.94345	.14812	89.72042
ACRP	ACRS	NUF					
SQ FT	SQ FT	NO OF G.S					

78.80837	10.97196	.45346

DIINP	.52000	N	10.00000	WINA	5.00000	TFP	-3.18304	OUT OF RANGE
DIINP	.52000	N	10.00000	WINA	6.00000	TFP	1.12752	OUT OF RANGE

DIINP	N	WINA	VIN	DIINH	WBRIX	DPIH	DIEHE
INCH		INCH	FT/SEC	INCH	FT	PSI	INCH
.52000	12.00000	5.00000	111.53071	1.27354	10.49966	.13322	.63677
DPEH	TTP	LCP	DPLCP	DIEP	FEFP	TFP	DIINS
PSI	INCH	FT	PSI	INCH		INCH	INCH
.44814	.05504	5.17751	1.62619	.18408	.48857	.04746	.90067
LCS	DPLCS	LSCS	LT	TFS	WINS	DISC	QTOTP
FT	PSI	FT	FT	INCH	INCH	INCH	B/HR
4.45679	.81309	2.82148	12.45578	.23479	8.93531	.10108	91549.42600
QTOTS	QSC	MT	MF	MIF	MHS	MLT	MCR
B/HR	B/HR	LBS	LBS	LBS	LBS	LBS	LBS
13049.24980	5359.43980	18.80619	72.39718	.00000	8.38308	.12883	99.63527
ACRP	ACRS	NUE					
SQ FT	SQ FT	NO OF G.S					
54.36206	11.31089	.53222					

FIGURE C-6 (cont'd)

DIINP	N	WINA	VIN	DIINH	WBRIX	DPIH	DIEHE
INCH		INCH	FT/SEC	INCH	FT	PSI	INCH
.52000	12.00000	6.00000	111.53071	1.27354	12.49751	.15886	.63677
DPEH	TTP	LCP	DPLCP	DIEP	FEFP	TFP	DIINS
PSI	INCH	FT	PSI	INCH		INCH	INCH
.53440	.05401	4.93986	1.55155	.18408	.43212	.04934	.90067
LCS	DPLCS	LSCS	LT	TFS	WINS	DISC	QTOTP
FT	PSI	FT	FT	INCH	INCH	INCH	B/HR
4.25223	.77577	2.69198	11.88406	.26226	9.46725	.10108	91549.42600
QTOTS	QSC	MT	MF	MIF	MHS	MLT	MCR
B/HR	B/HR	LBS	LBS	LBS	LBS	LBS	LBS
13049.24980	5359.43980	17.56588	83.48067	.00000	9.88297	.12291	111.05243
ACRP	ACRS	NUE					
SQ FT	SQ FT	NO OF G.S					
61.73597	11.40593	.55000					

DIINP	N	WINA	VIN	DIINH	WBRIX	DPIH	DIEHE
INCH		INCH	FT/SEC	INCH	FT	PSI	INCH
.52000	14.00000	5.00000	95.59775	1.37558	12.28042	.10777	.68779
DPEH	TTP	LCP	DPLCP	DIEP	FEFP	TFP	DIINS
PSI	INCH	FT	PSI	INCH		INCH	INCH
.36254	.06825	7.07431	1.69682	.18408	.26550	.01231	.97283
LCS	DPLCS	LSCS	LT	TFS	WINS	DISC	QTOTP
FT	PSI	FT	FT	INCH	INCH	INCH	B/HR
6.70633	.84841	4.24560	18.02624	.08630	5.30432	.10108	91549.42600
QTOTS	QSC	MT	MF	MIF	MHS	MLT	MCR

B/HR	B/HR	LBS	LBS	LBS	LBS	LBS	LBS
13849.24980	5359.43980	38.27731	27.28206	.00000	10.43577	.19385	76.18899
ACRP	ACRS	NUF					
SQ FT	SQ FT	NO OF G,S					
86.87547	10.46837	.33995					

DIINP	N	WINA	VIN	DIINH	WBRIX	DPIH	DIEHE
INCH		INCH	FT/SEC	INCH	FT	PSI	INCH
.52000	14.00000	6.00000	95.59775	1.37558	14.61174	.12852	.68779
DPEH	TTP	LCP	DPLCP	DIEP	FEFP	TFP	DTINS
PSI	INCH	FT	PSI	INCH		INCH	INCH
.43233	.06743	6.82255	1.63643	.18408	.23229	.01337	.97283
LCS	DPLCS	LSCS	LT	TFS	WINS	DISC	QTOTP
FT	PSI	FT	FT	INCH	INCH	INCH	B/HR
6.46767	.81821	4.09451	17.38473	.09424	5.54957	.10108	91549.42600
QTOTS	QSC	MT	MF	MIF	MHS	MLT	MCR
B/HR	B/HR	LBS	LBS	LBS	LBS	LBS	LBS
13849.24980	5359.43980	36.40658	32.14595	.00000	12.41690	.18695	81.15639
ACRP	ACRS	NUF					
SQ FT	SQ FT	NO OF G,S					
99.68936	10.52594	.34766					

FIGURE C-6 (cont'd)

SAMPLE INPUT DATA SHEET - FUEL CELL PERFORMANCE PROGRAM

FORTRAN DATA SHEET

COLS	1 - 10	11 - 20	21 - 30	31 - 40	41 - 50	51 - 60	61 - 70	71 - 80
1	SAMPLE CA	SE NØ 4, C	LØSED SAND	WICH FLAT	PLATE FUEL	CELL DIRE	CT RADIATØ	R
2	Nº OF SETS OF TS's 02							
3	Nº OF TS's IN 1ST SET 03							
4	TS 575.							
5	TS 530.							
6	TS 500.							
7	Nº OF TS's IN 2ND SET 03							
8	TS 500.							
9	TS 400.							
10	TS 300.							
11	N 15.	S 3.	DIIN .21	DOIN .40	WBARI 7.5	WBARE 7.5	TFIN .005	TFOUT .005
12	TOUTM 625.	PM 60.	ALPHS	ALPHT	KTH 80.	KF 80.	ET .92	EF .92
13	FSV .7	LC 7.	MTDG	MDG .0625	MDVIN .0738	TIN 800.	SHIN	
14	PUNT 3112							

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TITLE SAMPLE INPUT SHEET	ENGR.	PROJECT
PERFORMANCE ANALYSIS PROGRAM,	DATE	JOB NO.
H_2 - H_2O FUEL CELL DIRECT R/C	PAGE 1 OF 1 PAGES	

EDP SERVICES

Figure C-7

SAMPLE OUTPUT
FUEL CELL PERFORMANCE PROGRAM

PERFORMANCE ANALYSIS PROGRAM,H2 - H2O FUEL CELL, DIRECT R/C

SAMPLE CASE NO 4, CLOSED SANDWICH FLATPLATE FUEL CELL DIRECT RADIATOR

PUNT IS 3112

N	S	DIIN	DOIN	WBARI	WBARE	TFIN	TFOUT
		INCH	INCH	FT	FT	INCH	INCH
15.00000	3.00000	.21000	.40000	7.50000	7.50000	.00500	.00500

TOUTM	PM	ALPHS	ALPHT	KTH	KF	ET	EF
DEG R	PSIA			B/HR FT F	B/HR FT F		
625.00000	60.00000	-.00000	-.00000	80.00000	80.00000	.92000	.92000

FSV	LC	MDTG	MDG	MDVIN	TIN	SHIN
	FT	LBS/MIN	LBS/MIN	LBS/MIN	DEG R	
.70000	7.00000	-.00000	.05620	.07380	800.00000	-.00000

TOMIX	POMIX	S,NS	QTOT	QFT	QTT	TINSA	DPTM	SHOUT
DEG R	PSIA		B/HR	B/HR	B/HR	DEG R	PSI	
613.41909	3.68165	3.0	5517.24	5200.18	317.05	642.10905	.02673695	.59227108

	TS	MGI	MVI	MVE	TOU	NUE
	DEG R	LBS/MIN	LBS/MIN	LBS/MIN	DEG R	NO OF G.S
1	575.00000	.00367	.00481	.00304	625.71973	.13124
2	530.00000	.00376	.00494	.00190	607.46993	.08639
3	500.00000	.00382	.00501	.00135	594.16942	.07097

TOMIX	POMIX	S,NS	QTOT	QFT	QTT	TINSA	DPTM	SHOUT
DEG R	PSIA		B/HR	B/HR	B/HR	DEG R	PSI	
630.72321	5.70491	2.0	3572.77	3458.36	114.42	642.10905	.04327016	.95195553

	TS	MGI	MVI	MVE	TOU	NUE
	DEG R	LBS/MIN	LBS/MIN	LBS/MIN	DEG R	NO OF G.S
1	575.00000	.00545	.00715	.00587	635.10764	.35178
2	530.00000	.00579	.00761	.00474	625.29846	.24811

TOMIX	POMIX	S,NS	QTOT	QFT	QTT	TINSA	DPTM	SHOUT
DEG R	PSIA		B/HR	B/HR	B/HR	DEG R	PSI	
572.86373	1.31904	3.0	8433.45	7691.03	742.42	642.10905	.02547904	.20365211

	TS	MGI	MVI	MVE	TOU	NUE
	DEG R	LBS/MIN	LBS/MIN	LBS/MIN	DEG R	NO OF G.S
1	500.00000	.00364	.00477	.00117	590.40760	.06289
2	400.00000	.00376	.00494	.00036	543.02130	.04246
3	300.00000	.00384	.00504	.00016	510.47446	.03610

TOMIX	POMIX	S,NS	QTOT	QFT	QTT	TINSA	DPTM	SHOUT
DEG R	PSIA		B/HR	B/HR	B/HR	DEG R	PSI	
609.31056	3.31804	2.0	5868.40	5579.86	288.54	642.10905	.04079722	.53035242

TS	MGI	MVI	MVE	TOU	NUE

FIGURE C-8

	DEG R	LBS/MIN	LBS/MIN	LBS/MIN	DEG R	NO OF G,S
1	500.00000	.00562	.00738	.00373	617.60359	.19094
2	400.00000	.00562	.00738	.00196	593.56248	.12253

TOMIX DEG R	POMIX PSIA	S,NS	QTOT B/HR	QFT B/HR	QTT B/HR	TINSA DEG R	DPTM PSI	SHOUT
636.89239	6.66900	1.0	2742.20	2664.20	77.99	642.10905	.21448742	1.13294530

	TS DEG R	MGI LBS/MIN	MVI LBS/MIN	MVE LBS/MIN	TOU DEG R	NUE NO OF G,S
1	500.00000	.01124	.01476	.01273	636.89240	1.11797

FIGURE C-8 (cont'd)

SAMPLE INPUT DATA SHEET - ISOTHERMAL PERFORMANCE PROGRAM

FORTRAN DATA SHEET

COLS	1 - 10	11 - 20	21 - 30	31 - 40	41 - 50	51 - 60	61 - 70	71 - 80
1	SAMPLE CA	SE NØ 5A,	CENT FIN,	CYL, CØNST	INVENT, S	EGMENT, FL	UID-MERCUR	Y
	Nº OF SETS OF QIS & QIT							
2	01							
	Nº OF QIS & QIT IN 1ST SET							
3	06							
		QIS	QIT					
4	-1.0	430.	0.0					
		QIS	QIT					
5	-1.0	200.	0.0					
		QIS	QIT					
6	-1.0	70.	30.					
		QIS	QIT					
7	-1.0	150.	60.					
		QIS	QIT					
8	-1.0	70.	30.					
		QIS	QIT					
9	-1.0	200.	0.0					
	N	S	DIIN	DOIN	WBARI	WBARE	TFIN	TFOUT
10	24.	6.	.26	.50	16.	16.	.01	.01
	LT	LCG	HFG	M	R	PIR	TIR	KC
11	8.5	7.75	127.	200.	7.74	5.3	1041.	8.
	RHOL	VISL	CL	SUFT	CV	VISV	GAMMA	ALPHS
12	820.	.00059	.0326	.0326	.0249	.0000356	1.656	.2
	ALPHT	KTH	KF	ET	EF	FSV	NOS	PBP
13	.85	10.7	125.	.85	.85	.8	4.0	0.0
	MDT	XIN	TCG	TCAPG	TIMTC	TMIXG		
14	6.5	1.0	0.0	1000.	0.0	800.		
	PUNT							
15	1221							
16	SAMPLE CA	SE NØ 5B,	CENT FIN,	CYL, CØNST	PRESS, PR	ØP BY-PASS	, FLUID-ME	RCURY
	Nº OF SETS OF QIS & QIT							
17	01							
	Nº OF QIS & QIT IN 1ST SET							
18	06							
		QIS	QIT					
19	-1.0	430.	0.0					
		QIS	QIT					
20	-1.0	200.	0.0					

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	DATE	JOB NO.
	PAGE 1 OF 2 PAGES	

EDP SERVICES

Figure C-9

FORTRAN DATA SHEET

COLS	1 - 10	11 - 20	21 - 30	31 - 40	41 - 50	51 - 60	61 - 70	71 - 80
21	-1.0	QIS 70.	QIT 30.					
22	-1.0	QIS 150.	QIT 60.					
23	-1.0	QIS 70.	QIT 30.					
24	-1.0	QIS 200.	QIT 0.0					
25	N 24.	S 6.	DIIN .26	DOIN .50	WBARI 16.	WBARE 16.	TFIN .01	TFOUT .01
26	LT 9.	LCG 0.0	HFG 127.	M 200.	R 7.74	PIR 5.3	TIR 1041.	KC 8.
27	RHOL 820.	VISL .00059	CL .0326	SUFT .0326	CV .0249	VISV .0000356	GAMMA 1.656	ALPHS .2
28	ALPHT .85	KTH 10.7	KF 125.	ET .85	EF .85	ESV .8	NOS 4.0	PBP 1.0
29	MDT 13.1	XIN 1.0	TCG 1060.	TCAPG 0.0	TIMTC 0.0	TMIXG 850.		
30	PUNT 1221							

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ENGR. | DATE | PAGE 2 OF 2 PAGES | PROJECT | JOB NO.

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Figure C-9 (cont'd)

SAMPLE OUTPUT
ISOTHERMAL PERFORMANCE PROGRAM

```
SAMPLE CASE NO. 5A, CENT FIN, CYL, CONST INVENT, SEGMENT, FLUID-MERCURY
PERFORMANCE ANALYSIS PROGRAM ,ISO-THERMAL DIRECT R/C  W/SC
FIXED INPUT
        N          S        DIIN       DOIN      WBARI      WBARE       TFIN      TFOUT         LT        LCG        HFG          M
                            INCH       INCH         FT         FT       INCH       INCH         FT         FT      B/LB
  24.0000     6.0000      .2600      .5000    16.0000    16.0000      .0100      .0100     8.5000     7.7500   127.0000   200.0000
        R        PIR        TIR         KC       RHOL       VISL         CL       SUFT         CV       VISV      GAMMA      ALPHS
     FT/R       PSIA      DEG R B/HR FT F LBS/CU.FT LB/FT SEC     B/LB F    LBS/FT    B/LBS F LB/FT SEC
   7.7400     5.3000  1041.0000     8.0000   820.0000   .0005900   .0326000   .0326000   .0249000   .0000356  1.6560000   .2000000
    ALPHT        KTH         KF         FT         EF        FSV        NOS        PBP        MDT        XIN        TCG      TCAPG
           B/HR FT F  B/HR FT F                                                        LBS/MIN                  DEG R      DEG R
    .8500    10.7000   125.0000      .8500      .8500      .8000     4.0000      .0000     6.5000     1.0000     -.0000  1000.0000
    TIMTC      TMIXG
    DEG R      DEG R
   -.0000   800.0000


 RUNT IS  1221

 GROUP  1 VALUE OF TS AVG. IS    400.0 DEG R

 MACH       3.30  IS TOO HIGH--WARNING

 SET NO.   0
             TC             PC             LC            LSC           TOUT          DPTOT            NUF            NPG
          DEG R           PSIA             FT             FT          DEG R            PSI      NO OF G,S      NO OF G,S
      840.65797         .28447        7.75000         .75000      641.98139       11.25454         .52343        2.00103
          QTOTC          QTOTS           QTOT            ML1            MDS            VIN           MACH             TS
           B/HR           B/HR           B/HR            LBS        LBS/MIN         FT/SEC                         DEG R
        8255.00         421.00        8676.00        1.71192        1.08333     1943.66290        3.30238      400.02448

 MACH       3.12  IS TOO HIGH--WARNING

 SET NO.   1
             TC             PC             LC            LSC           TOUT          DPTOT            NUF            NPG
          DEG R           PSIA             FT             FT          DEG R            PSI      NO OF G,S      NO OF G,S
      842.42973         .29370        8.11291         .38709      725.00475       10.89643         .49400        3.80457
          QTOTC          QTCTS           QTOT            ML1            MDS            VIN           MACH             TS
           B/HR           B/HR           B/HR            LBS        LBS/MIN         FT/SEC                         DEG R
        8039.95         242.34        8282.29        1.27338        1.05511     1837.34250        3.11846      492.81850

 MACH       3.28  IS TOO HIGH--WARNING

 SET NO.   2
             TC             PC             LC            LSC           TOUT          DPTOT            NUF            NPG
          DEG R           PSIA             FT             FT          DEG R            PSI      NO OF G,S      NO OF G,S
      840.96175         .28603        7.76377         .73623      645.31966       11.19136         .51999        2.02811
          QTOTC          GTCTS           QTOT            ML1            MDS            VIN           MACH             TS
           B/HR           B/HR           B/HR            LBS        LBS/MIN         FT/SEC                         DEG R
        8244.61         414.04        8658.65        1.69528        1.08197     1931.28550        3.28076      406.98406

 MACH       3.38  IS TOO HIGH--WARNING
```

FIGURE C-10

```
SET NO.  3
        TC            PC            LC            LSC           TOUT          DPTOT         NUE           NPG
     DEG R          PSIA            FT             FT          DEG R           PSI      NO OF G,S     NO OF G,S
  840.00636        .28113       7.58284         .91716     606.57563      11.38518        .53573       1.64426
     QTOTC         QTOTS          QTOT            ML1            MDS           VIN          MACH            TS
      B/HR          B/HR          B/HR            LBS        LBS/MIN        FT/SEC                       DEG R
   8356.45        500.72       8857.17        1.91392        1.09665    1989.34020       3.38130     313.03608

MACH      3.32  IS TOO HIGH--WARNING

SET NO.  4
        TC            PC            LC            LSC           TOUT          DPTOT         NUE           NPG
     DEG R          PSIA            FT             FT          DEG R           PSI      NO OF G,S     NO OF G,S
  840.60618        .28420       7.69288         .80712     630.12390      11.26328        .52594       1.88668
     QTOTC         QTOTS          QTOT            ML1            MDS           VIN          MACH            TS
      B/HR          B/HR          B/HR            LBS        LBS/MIN        FT/SEC                       DEG R
   8287.94        447.79       8735.73        1.78095        1.08766    1953.12570       3.31856     378.74132

MACH      3.38  IS TOO HIGH--WARNING

SET NO.  5
        TC            PC            LC            LSC           TOUT          DPTOT         NUE           NPG
     DEG R          PSIA            FT             FT          DEG R           PSI      NO OF G,S     NO OF G,S
  840.00675        .28113       7.58284         .91716     606.57595      11.38510        .53572       1.64425
     QTOTC         QTOTS          QTOT            ML1            MDS           VIN          MACH            TS
      B/HR          B/HR          B/HR            LBS        LBS/MIN        FT/SEC                       DEG R
   8356.45        500.72       8857.17        1.91392        1.09665    1989.32670       3.38128     313.03608

MACH      3.28  IS TOO HIGH--WARNING

SET NO.  6
        TC            PC            LC            LSC           TOUT          DPTOT         NUE           NPG
     DEG R          PSIA            FT             FT          DEG R           PSI      NO OF G,S     NO OF G,S
  840.96216        .28603       7.76377         .73623     645.31995      11.19129        .51999       2.02810
     QTOTC         QTOTS          QTOT            ML1            MDS           VIN          MACH            TS
      B/HR          B/HR          B/HR            LBS        LBS/MIN        FT/SEC                       DEG R
   8244.61        414.04       8658.65        1.69528        1.08197    1931.27240       3.28074     406.98406

      NS,S         THETA         TOMIX          TMIXX           DPTM           TCM          PPWR
                                 DEG R          DEG R            PSI         DEG R            HP
   6.00000        .00000     643.44870         .00000       11.24971     840.82326        .00038

GROUP  1 VALUE OF TS AVG. IS   398.6 DEG R

MACH      1.78  IS TOO HIGH--WARNING

SET NO.  0
        TC            PC            LC            LSC           TOUT          DPTOT         NUE           NPG
     DEG R          PSIA            FT             FT          DEG R           PSI      NO OF G,S     NO OF G,S
  889.09607        .65105       7.75000         .75000     681.79438       7.80507        .37524       1.42433
     QTOTC         QTOTS          QTOT            ML1            MDS           VIN          MACH            TS
      B/HR          B/HR          B/HR            LBS        LBS/MIN        FT/SEC                       DEG R
```

FIGURE C-10 (cont'd)

9906.00	527.13	10433.13	1.71192	1.30000	1077.81340	1.78068	398.58813

MACH 1.70 IS TOO HIGH--WARNING

SET NO. 1

TC	PC	LC	LSC	TOUT	DPTOT	NUE	NPG
DEG R	PSIA	FT	FT	DEG R	PSI	NO OF G,S	NO OF G,S
890.86466	.66989	8.03675	.46325	750.48288	7.62254	.35924	2.27674
QTOTC	QTOTS	QTOT	ML1	MDS	VIN	MACH	TS
B/HR	B/HR	B/HR	LBS	LBS/MIN	FT/SEC		DEG R
9700.72	349.57	10050.28	1.36541	1.27306	1027.83340	1.69642	492.81850

MACH 1.77 IS TOO HIGH--WARNING

SET NO. 2

TC	PC	LC	LSC	TOUT	DPTOT	NUE	NPG
DEG R	PSIA	FT	FT	DEG R	PSI	NO OF G,S	NO OF G,S
889.37802	.65403	7.76418	.73582	685.36454	7.77120	.37326	1.44630
QTOTC	QTOTS	QTOT	ML1	MDS	VIN	MACH	TS
B/HR	B/HR	B/HR	LBS	LBS/MIN	FT/SEC		DEG R
9893.88	518.13	10412.01	1.69479	1.29841	1071.94200	1.77070	406.98406

MACH 1.82 IS TOO HIGH--WARNING

SET NO. 3

TC	PC	LC	LSC	TOUT	DPTOT	NUE	NPG
DEG R	PSIA	FT	FT	DEG R	PSI	NO OF G,S	NO OF G,S
888.42928	.64407	7.62029	.87971	652.27155	7.86988	.38174	1.21799
QTOTC	QTOTS	QTOT	ML1	MDS	VIN	MACH	TS
B/HR	B/HR	B/HR	LBS	LBS/MIN	FT/SEC		DEG R
10000.20	606.21	10606.41	1.86866	1.31236	1099.03650	1.81642	313.03608

MACH 1.79 IS TOO HIGH--WARNING

SET NO. 4

TC	PC	LC	LSC	TOUT	DPTOT	NUE	NPG
DEG R	PSIA	FT	FT	DEG R	PSI	NO OF G,S	NO OF G,S
889.02246	.65028	7.70802	.79198	672.43785	7.80786	.37647	1.34706
QTOTC	QTOTS	QTOT	ML1	MDS	VIN	MACH	TS
B/HR	B/HR	B/HR	LBS	LBS/MIN	FT/SEC		DEG R
9935.01	552.34	10487.35	1.76266	1.30381	1082.16720	1.78795	378.74132

MACH 1.82 IS TOO HIGH--WARNING

SET NO. 5

TC	PC	LC	LSC	TOUT	DPTOT	NUE	NPG
DEG R	PSIA	FT	FT	DEG R	PSI	NO OF G,S	NO OF G,S
888.42960	.64407	7.62029	.87971	652.27132	7.86984	.38175	1.21799
QTOTC	QTOTS	QTOT	ML1	MDS	VIN	MACH	TS
B/HR	B/HR	B/HR	LBS	LBS/MIN	FT/SEC		DEG R
10000.20	606.21	10606.42	1.86866	1.31236	1099.03110	1.81641	313.03608

FIGURE C-10 (cont'd)

NS.S	THETA	TOMIX	TMIXX	DPTM	TCM	PPWR
		DEG R	DEG R	PSI	DEG R	HP
5.00000	.00000	675.73646	.00000	7.80262	889.22682	.00026

GROUP 1 VALUE OF TS AVG. IS 413.2 DEG R

MACH .84 IS TOO HIGH--WARNING

SET NO. 0

TC	PC	LC	LSC	TOUT	DPTOT	NUE	NPG
DEG R	PSIA	FT	FT	DEG R	PSI	NO OF G,S	NO OF G,S
956.04108	1.78080	7.75000	.75000	739.44292	4.41834	.20884	.80031
QTOTC	QTOTS	QTOT	ML1	MDS	VIN	MACH	TS
B/HR	B/HR	B/HR	LBS	LBS/MIN	FT/SEC		DEG R
12382.50	688.46	13070.96	1.71192	1.62500	529.64400	.84384	413.19936

MACH .82 IS TOO HIGH--WARNING

SET NO. 1

TC	PC	LC	LSC	TOUT	DPTOT	NUE	NPG
DEG R	PSIA	FT	FT	DEG R	PSI	NO OF G,S	NO OF G,S
957.56295	1.81903	7.93592	.56408	786.44668	4.34199	.20276	1.05359
QTOTC	QTOTS	QTOT	ML1	MDS	VIN	MACH	TS
B/HR	B/HR	B/HR	LBS	LBS/MIN	FT/SEC		DEG R
12214.67	536.52	12751.19	1.48725	1.60298	512.29995	.81556	492.81850

MACH .84 IS TOO HIGH--WARNING

SET NO. 2

TC	PC	LC	LSC	TOUT	DPTOT	NUE	NPG
DEG R	PSIA	FT	FT	DEG R	PSI	NO OF G,S	NO OF G,S
956.05831	1.78123	7.73737	.76263	736.48965	4.41599	.20890	.78622
QTOTC	QTOTS	QTOT	ML1	MDS	VIN	MACH	TS
B/HR	B/HR	B/HR	LBS	LBS/MIN	FT/SEC		DEG R
12392.82	698.48	13091.30	1.72719	1.62635	529.98716	.84435	406.98406

MACH .86 IS TOO HIGH--WARNING

SET NO. 3

TC	PC	LC	LSC	TOUT	DPTOT	NUE	NPG
DEG R	PSIA	FT	FT	DEG R	PSI	NO OF G,S	NO OF G,S
955.12240	1.75805	7.63066	.86934	709.99751	4.46349	.21260	.69398
QTOTC	QTOTS	QTOT	ML1	MDS	VIN	MACH	TS
B/HR	B/HR	B/HR	LBS	LBS/MIN	FT/SEC		DEG R
12491.55	785.99	13277.55	1.85614	1.63931	540.70078	.86187	313.03608

MACH .85 IS TOO HIGH--WARNING

SET NO. 4

TC	PC	LC	LSC	TOUT	DPTOT	NUE	NPG
DEG R	PSIA	FT	FT	DEG R	PSI	NO OF G,S	NO OF G,S
955.70619	1.77248	7.69587	.80413	726.19741	4.43373	.21030	.74734
QTOTC	QTOTS	QTOT	ML1	MDS	VIN	MACH	TS

FIGURE C-10 (cont'd)

```
         B/HR          B/HR          B/HR          LBS       LBS/MIN        FT/SEC                     DEG R
     12430.96        732.35      13163.30       1.77733       1.63136     534.02525       .85097     378.74132

         NS,S         THETA         TOMIX         TMIXX          DPTM           TCM         PPWR
                                    DEG R         DEG R           PSI         DEG R           HP
      4.00000        .00000     736.66240        .00000       4.41758     956.11961       .00015

  GROUP  1 VALUE OF TS AVG. IS    423.0 DEG R

  SET NO.  0
           TC            PC            LC           LSC          TOUT        DPTOT          NUE          NPG
        DEG R          PSIA            FT            FT         DEG R          PSI   NO OF G,S    NO OF G,S
   1050.87440       5.94784       7.75000        .75000     822.90971      2.79601       .13929       .52715
        GTOTC         GTOTS          GTOT           ML1           MDS          VIN         MACH           TS
         B/HR          B/HR          B/HR           LBS       LBS/MIN       FT/SEC                     DEG R
     16510.00        966.11      17476.11       1.71192       2.16667    232.40858       .35318    422.97440

  SET NO.  1
           TC            PC            LC           LSC          TOUT        DPTOT          NUF          NPG
        DEG R          PSIA            FT            FT         DEG R          PSI   NO OF G,S    NO OF G,S
   1052.19330       6.03918       7.86291        .63709     853.93096      2.75822       .13619       .61437
        GTOTC         GTOTS          GTOT           ML1           MDS          VIN         MACH           TS
         B/HR          B/HR          B/HR           LBS       LBS/MIN       FT/SEC                     DEG R
     16373.20        833.27      17206.48       1.57549       2.14871    227.28197       .34517    492.81850

  SET NO.  2
           TC            PC            LC           LSC          TOUT        DPTOT          NUE          NPG
        DEG R          PSIA            FT            FT         DEG R          PSI   NO OF G,S    NO OF G,S
   1050.71780       5.93708       7.72986        .77014     817.53119      2.80017       .13972       .51379
        GTOTC         GTOTS          GTOT           ML1           MDS          VIN         MACH           TS
         B/HR          B/HR          B/HR           LBS       LBS/MIN       FT/SEC                     DEG R
     16533.65        989.66      17523.31       1.73526       2.16977    233.12889       .35430    406.98406

  SET NO.  3
           TC            PC            LC           LSC          TOUT        DPTOT          NUE          NPG
        DEG R          PSIA            FT            FT         DEG R          PSI   NO OF G,S    NO OF G,S
   1049.82210       5.87580       7.65718        .84282     797.66153      2.82605       .14181       .47269
        GTOTC         GTOTS          GTOT           ML1           MDS          VIN         MACH           TS
         B/HR          B/HR          B/HR           LBS       LBS/MIN       FT/SEC                     DEG R
     16623.15       1075.98      17699.13       1.82409       2.18152    236.63318       .35978    313.03608

         NS,S         THETA         TOMIX         TMIXX          DPTM           TCM         PPWR
                                    DEG R         DEG R           PSI         DEG R           HP
      3.00000        .00000     817.29421        .00000       2.79574    1050.92330       .00009
  SAMPLE CASE NO. 5H, CENT FIN, CYL, CONST PRESS, PROP BYPASS, FLUID-MERCURY
  PERFORMANCE ANALYSIS PROGRAM ,ISO-THERMAL DIRECT R/C  W/SC
  FIXED INPUT
         N          S       DIIN      DOIN      WBARI      WBARE      TFIN     TFOUT        LT       LCG        HFG          M
                            INCH      INCH         FT         FT      INCH      INCH        FT        FT       B/LB
   24.0000     6.0000      .2600     .5000    16.0000    16.0000     .0100     .0100    9.0000     .0000   127.0000   200.0000
         R        PIR        TIR        KC       RHOL       VISL        CL      SUFT        CV      VISV      GAMMA      ALPHS
      FT/R       PSIA      DEG R  B/HR FT F  LBS/CU,FT  LB/FT SEC    B/LB F    LBS/FT  B/LBS F  LB/FT SEC
```

FIGURE C-10 (cont'd)

7.7400	5.3000	1041.0000	8.0000	820.0000	.0005900	.0326000	.0326000	.0249000	.0000356	1.6560000	.2000000
ALPHY	KTH	KF	FT	FF	FSV	NOS	PBP	MDT	XIN	TCG	TCAPG
	B/HR FT F	B/HR FT F						LBS/MIN		DEG R	DEG R
.8500	10.7000	125.0000	.8500	.8500	.8000	4.0000	1.0000	13.1000	1.0000	1060.0000	.0000
TIMTC	TMIXG										
DEG R	DEG R										
.0000	850.0000										

PUNT IS 1221

GROUP 1 VALUE OF TS AVG. IS 400.0 DEG R

SET NO. 0

TC	PC	LC	LSC	TOUT	DPTOT	NUE	NPG
DEG R	PSIA	FT	FT	DEG R	PSI	NO OF G,S	NO OF G,S
1059.50930	6.56736	5.67390	3.32610	572.44392	.99394	.05420	.03639
QTOTC	QTOTS	QTOT	ML1	MDS	VIN	MACH	TS
B/HR	B/HR	B/HR	LBS	LBS/MIN	FT/SEC		DEG R
12477.75	1560.05	14037.80	4.82494	1.63750	160.38508	.24273	400.02448

SET NO. 1

TC	PC	LC	LSC	TOUT	DPTOT	NUE	NPG
DEG R	PSIA	FT	FT	DEG R	PSI	NO OF G,S	NO OF G,S
1061.06030	6.68415	5.77386	3.22614	605.53628	.98023	.05327	.03732
QTOTC	QTOTS	QTOT	ML1	MDS	VIN	MACH	TS
B/HR	B/HR	B/HR	LBS	LBS/MIN	FT/SEC		DEG R
12354.26	1444.58	13798.84	4.70414	1.62129	156.25154	.23630	492.81850

SET NO. 2

TC	PC	LC	LSC	TOUT	DPTOT	NUE	NPG
DEG R	PSIA	FT	FT	DEG R	PSI	NO OF G,S	NO OF G,S
1059.59830	6.57402	5.67937	3.32063	574.35532	.99320	.05415	.03644
QTOTC	QTOTS	QTOT	ML1	MDS	VIN	MACH	TS
B/HR	B/HR	B/HR	LBS	LBS/MIN	FT/SEC		DEG R
12471.29	1553.40	14024.69	4.81832	1.63665	160.15326	.24237	406.98406

SET NO. 3

TC	PC	LC	LSC	TOUT	DPTOT	NUE	NPG
DEG R	PSIA	FT	FT	DEG R	PSI	NO OF G,S	NO OF G,S
1058.70970	6.50783	5.62770	3.37230	555.26496	1.00127	.05468	.03601
QTOTC	QTOTS	QTOT	ML1	MDS	VIN	MACH	TS
B/HR	B/HR	B/HR	LBS	LBS/MIN	FT/SEC		DEG R
12536.60	1620.11	14156.71	4.88076	1.64522	162.49293	.24602	313.03608

SET NO. 4

TC	PC	LC	LSC	TOUT	DPTOT	NUE	NPG
DEG R	PSIA	FT	FT	DEG R	PSI	NO OF G,S	NO OF G,S
1059.26190	6.54890	5.65935	3.34065	567.14959	.99674	.05435	.03627
QTOTC	QTOTS	QTOT	ML1	MDS	VIN	MACH	TS
B/HR	B/HR	B/HR	LBS	LBS/MIN	FT/SEC		DEG R

FIGURE C-10 (cont'd)

12496.48	1578.58	14075.06	4.84251	1.63996	161.04107	.24375	378.74132
SET NO. 5							
TC	PC	LC	LSC	TOUT	DPTOT	NUE	NPG
DEG R	PSIA	FT	FT	DEG R	PSI	NO OF G,S	NO OF G,S
1058.71010	6.50786	5.62770	3.37230	555.26491	1.00127	.05468	.03601
QTOTC	QTOTS	QTOT	ML1	MDS	VIN	MACH	TS
B/HR	B/HR	B/HR	LBS	LBS/MIN	FT/SEC		DEG R
12536.60	1620.11	14156.71	4.88076	[illegible]	182.49277	.24601	313.03608
SET NO. 6							
TC	PC	LC	LSC	TOUT	DPTOT	NUE	NPG
DEG R	PSIA	FT	FT	DEG R	PSI	NO OF G,S	NO OF G,S
1059.59730	6.57394	5.67937	3.32063	574.35584	.99321	.05415	.03644
QTOTC	QTCTS	QTOT	ML1	MDS	VIN	MACH	TS
B/HR	B/HR	B/HR	LBS	LBS/MIN	FT/SEC		DEG R
12471.29	1553.40	14024.69	4.81832	1.63665	160.15484	.24237	406.98406
NS,S	THETA	TOMIX	TMIXX	DPTM	TCM	PPWR	
		DEG R	DEG R	PSI	DEG R	HP	
6.00000	-.01857	572.20088	1667.97630	.99400	.00000	.00007	
SET NO. 0							
TC	PC	LC	LSC	TOUT	DPTOT	NUE	NPG
DEG R	PSIA	FT	FT	DEG R	PSI	NO OF G,S	NO OF G,S
1059.78380	6.58791	7.71898	1.28102	737.62202	2.65473	.13252	.29277
QTOTC	QTOTS	QTOT	ML1	MDS	VIN	MACH	TS
B/HR	B/HR	B/HR	LBS	LBS/MIN	FT/SEC		DEG R
16945.90	1401.37	18347.27	2.35361	2.72387	217.19418	.32867	406.98406
SET NO. 1							
TC	PC	LC	LSC	TOUT	DPTOT	NUE	NPG
DEG R	PSIA	FT	FT	DEG R	PSI	NO OF G,S	NO OF G,S
1061.24500	6.69817	7.84320	1.15680	767.67819	2.81234	.12914	.32030
QTOTC	QTOTS	QTOT	ML1	MDS	VIN	MACH	TS
B/HR	B/HR	B/HR	LBS	LBS/MIN	FT/SEC		DEG R
16778.37	1264.36	18042.73	2.20351	2.20189	211.79855	.32028	492.81850
SET NO. 2							
TC	PC	LC	LSC	TOUT	DPTOT	NUE	NPG
DEG R	PSIA	FT	FT	DEG R	PSI	NO OF G,S	NO OF G,S
1059.78320	6.58786	7.71499	1.28501	737.07847	2.65094	.13237	.29141
QTOTC	QTOTS	QTOT	ML1	MDS	VIN	MACH	TS
B/HR	B/HR	B/HR	LBS	LBS/MIN	FT/SEC		DEG R
16937.14	1403.00	18340.14	2.35844	2.72272	217.08324	.32850	406.98406
SET NO. 3							
TC	PC	LC	LSC	TOUT	DPTOT	NUE	NPG
DEG R	PSIA	FT	FT	DEG R	PSI	NO OF G,S	NO OF G,S
1058.89710	6.52174	7.64487	1.35513	719.65440	2.67472	.13429	.27816
QTOTC	QTOTS	QTOT	ML1	MDS	VIN	MACH	TS
B/HR	B/HR	B/HR	LBS	LBS/MIN	FT/SEC		DEG R

FIGURE C-10 (cont'd)

17025.73	1482.62	18508.36	2.44317	2.23435	220.24704	.33343	313.03608
SET NO. 4							
TC	PC	LC	LSC	TOUT	DPTOT	NUE	NPG
DEG R	PSIA	FT	FT	DEG R	PSI	NO OF G.S	NO OF G.S
1059.44730	6.56274	7.68783	1.31217	730.39631	2.65992	.13310	.28609
QTOTC	QTOTS	QTOT	ML1	MDS	VIN	MACH	TS
B/HR	B/HR	B/HR	LBS	LBS/MIN	FT/SEC		DEG R
16971.31	1433.48	18404.79	2.39127	2.22721	218.28488	.33037	378.74132
SET NO. 5							
TC	PC	LC	LSC	TOUT	DPTOT	NUE	NPG
DEG R	PSIA	FT	FT	DEG R	PSI	NO OF G.S	NO OF G.S
1058.89730	6.52175	7.64487	1.35513	719.65455	2.67471	.13429	.27816
QTOTC	QTOTS	QTOT	ML1	MDS	VIN	MACH	TS
B/HR	B/HR	B/HR	LBS	LBS/MIN	FT/SEC		DEG R
17025.73	1482.62	18508.36	2.44317	2.23435	220.24658	.33343	313.03608
SET NO. 6							
TC	PC	LC	LSC	TOUT	DPTOT	NUE	NPG
DEG R	PSIA	FT	FT	DEG R	PSI	NO OF G.S	NO OF G.S
1059.78300	6.58785	7.71499	1.28501	737.07806	2.65095	.13237	.29141
QTOTC	QTOTS	QTOT	ML1	MDS	VIN	MACH	TS
B/HR	B/HR	B/HR	LBS	LBS/MIN	FT/SEC		DEG R
16937.14	1403.01	18340.14	2.35844	2.22272	217.08356	.32850	406.98406
NS.S	THETA	TOMIX	TMIXX	DPTM	TCM	PPWR	
		DEG R	DEG R	PSI	DEG R	HP	
6.00000	.04473	735.55772	657.20578	2.65096	.00000	.00018	
SET NO. 0							
TC	PC	LC	LSC	TOUT	DPTOT	NUE	NPG
DEG R	PSIA	FT	FT	DEG R	PSI	NO OF G.S	NO OF G.S
1059.71920	6.58307	7.23928	1.76072	681.55790	2.27406	.11564	.17552
QTOTC	QTOTS	QTOT	ML1	MDS	VIN	MACH	TS
B/HR	B/HR	B/HR	LBS	LBS/MIN	FT/SEC		DEG R
15892.77	1542.73	17435.51	2.93330	2.08567	203.83370	.30846	406.98406
SET NO. 1							
TC	PC	LC	LSC	TOUT	DPTOT	NUE	NPG
DEG R	PSIA	FT	FT	DEG R	PSI	NO OF G.S	NO OF G.S
1061.18000	6.69324	7.35580	1.64420	709.71315	2.18859	.11275	.18576
QTOTC	QTOTS	QTOT	ML1	MDS	VIN	MACH	TS
B/HR	B/HR	B/HR	LBS	LBS/MIN	FT/SEC		DEG R
15735.61	1419.65	17155.27	2.73249	2.06504	198.76981	.30059	492.81850
SET NO. 2							
TC	PC	LC	LSC	TOUT	DPTOT	NUE	NPG
DEG R	PSIA	FT	FT	DEG R	PSI	NO OF G.S	NO OF G.S
1059.72850	6.58317	7.23553	1.76447	681.18464	2.22084	.11551	.17487
QTOTC	QTOTS	QTOT	ML1	MDS	VIN	MACH	TS
B/HR	B/HR	B/HR	LBS	LBS/MIN	FT/SEC		DEG R

FIGURE C-10 (cont'd)

```
     15884.55       1543.46      17428.01       2.93783       2.08459     203.72539        .30829     406.98406

  SET NO.  3
           TC            PC            LC           LSC          TOUT        DPTOT           NUF           NPG
        DEG R          PSIA            FT            FT         DEG R          PSI     NO OF G,S     NO OF G,S
   1058.83400       6.51705       7.16975       1.83025     664.47461      2.24075        .11715        .16967
        QTOTC         QTOTS          QTOT           ML1           MDS          VIN          MACH            TS
         B/HR          B/HR          B/HR           LBS       LBS/MIN       FT/SEC                       DEG R
     15967.66       1616.39      17584.05       3.01732       2.09549     206.69601        .31292     313.03608

  SET NO.  4
           TC            PC            LC           LSC          TOUT        DPTOT           NUF           NPG
        DEG R          PSIA            FT            FT         DEG R          PSI     NO OF G,S     NO OF G,S
   1059.38400       6.55801       7.21005       1.78995     674.81440      2.22837        .11613        .17280
        QTOTC         QTOTS          QTOT           ML1           MDS          VIN          MACH            TS
         B/HR          B/HR          B/HR           LBS       LBS/MIN       FT/SEC                       DEG R
     15916.61       1571.23      17487.84       2.96862       2.08879     204.85474        .31005     378.74132

  SET NO.  5
           TC            PC            LC           LSC          TOUT        DPTOT           NUF           NPG
        DEG R          PSIA            FT            FT         DEG R          PSI     NO OF G,S     NO OF G,S
   1058.83340       6.51701       7.16975       1.83025     664.47637      2.24077        .11715        .16967
        QTOTC         QTOTS          QTOT           ML1           MDS          VIN          MACH            TS
         B/HR          B/HR          B/HR           LBS       LBS/MIN       FT/SEC                       DEG R
     15967.66       1616.39      17584.05       3.01732       2.09549     206.69731        .31292     313.03608

  SET NO.  6
           TC            PC            LC           LSC          TOUT        DPTOT           NUF           NPG
        DEG R          PSIA            FT            FT         DEG R          PSI     NO OF G,S     NO OF G,S
   1059.72050       6.58317       7.23553       1.76447     681.18402      2.22084        .11551        .17487
        QTOTC         QTOTS          QTOT           ML1           MDS          VIN          MACH            TS
         B/HR          B/HR          B/HR           LBS       LBS/MIN       FT/SEC                       DEG R
     15884.55       1543.46      17428.02       2.93783       2.08459     203.72546        .30829     406.98406

         NS,S         THETA         TOMIX         TMIXX          DPTM          TCM          PPWR
                                    DEG R         DEG R           PSI        DEG R            HP
      6.00000        .03789     679.58498     870.85717       2.22089       .00000        .00015

  SET NO.  0
           TC            PC            LC           LSC          TOUT        DPTOT           NUF           NPG
        DEG R          PSIA            FT            FT         DEG R          PSI     NO OF G,S     NO OF G,S
   1059.72650       6.58361       7.29117       1.70883     686.83814      2.26827        .11741        .18480
        QTOTC         QTOTS          QTOT           ML1           MDS          VIN          MACH            TS
         B/HR          B/HR          B/HR           LBS       LBS/MIN       FT/SEC                       DEG R
     16006.70       1532.13      17538.83       2.87059       2.10062     205.27931        .31065     406.98406

  SET NO.  1
           TC            PC            LC           LSC          TOUT        DPTOT           NUF           NPG
        DEG R          PSIA            FT            FT         DEG R          PSI     NO OF G,S     NO OF G,S
   1061.18730       6.69379       7.40853       1.59147     715.08266      2.23209        .11448        .19610
        QTOTC         QTOTS          QTOT           ML1           MDS          VIN          MACH            TS
         B/HR          B/HR          B/HR           LBS       LBS/MIN       FT/SEC                       DEG R
```

FIGURE C-10 (cont'd)

15848.42	1408.02	17256.44	2.72877	2.07985	200.17963	.30272	492.81850

SET NO. 2

TC	PC	LC	LSC	TOUT	DPTOT	NUF	NPG
DEG R	PSIA	FT	FT	DEG R	PSI	NO OF G,S	NO OF G,S
1059.72640	6.58361	7.28740	1.71260	686.44930	2.26502	.11728	.18410
QTOTC	QTOTS	QTOT	ML1	MDS	VIN	MACH	TS
B/HR	B/HR	B/HR	LBS	LBS/MIN	FT/SEC		DEG R
15998.42	1532.93	17531.35	2.87515	2.09953	205.17321	.31048	406.98406

SET NO. 3

TC	PC	LC	LSC	TOUT	DPTOT	NUF	NPG
DEG R	PSIA	FT	FT	DEG R	PSI	NO OF G,S	NO OF G,S
1058.84010	6.51750	7.22115	1.77885	669.72160	2.28532	.11895	.17839
QTOTC	QTOTS	QTOT	ML1	MDS	VIN	MACH	TS
B/HR	B/HR	B/HR	LBS	LBS/MIN	FT/SEC		DEG R
16082.13	1606.35	17688.48	2.95520	2.11052	208.16439	.31514	313.03608

SET NO. 4

TC	PC	LC	LSC	TOUT	DPTOT	NUF	NPG
DEG R	PSIA	FT	FT	DEG R	PSI	NO OF G,S	NO OF G,S
1059.38990	6.55845	7.26174	1.73826	680.06778	2.27270	.11792	.18182
QTOTC	QTOTS	QTOT	ML1	MDS	VIN	MACH	TS
B/HR	B/HR	B/HR	LBS	LBS/MIN	FT/SEC		DEG R
16030.71	1560.90	17591.61	2.90616	2.10377	206.31056	.31226	378.74132

SET NO. 5

TC	PC	LC	LSC	TOUT	DPTOT	NUF	NPG
DEG R	PSIA	FT	FT	DEG R	PSI	NO OF G,S	NO OF G,S
1058.84010	6.51750	7.22115	1.77885	669.72159	2.28532	.11895	.17839
QTOTC	QTOTS	QTOT	ML1	MDS	VIN	MACH	TS
B/HR	B/HR	B/HR	LBS	LBS/MIN	FT/SEC		DEG R
16082.13	1606.35	17688.48	2.95520	2.11052	208.16439	.31514	313.03608

SET NO. 6

TC	PC	LC	LSC	TOUT	DPTOT	NUF	NPG
DEG R	PSIA	FT	FT	DEG R	PSI	NO OF G,S	NO OF G,S
1059.72600	6.58358	7.28740	1.71260	686.44852	2.26503	.11728	.18410
QTOTC	QTOTS	QTOT	ML1	MDS	VIN	MACH	TS
B/HR	B/HR	B/HR	LBS	LBS/MIN	FT/SEC		DEG R
15998.42	1532.93	17531.35	2.87515	2.09953	205.17404	.31049	406.98406

NS.S	THETA	TOMIX	TMIXX	DPTM	TCM	PPWR
		DEG R	DEG R	PSI	DEG R	HP
6.00000	.03789	684.86121	846.65250	2.26504	.00000	.00015

FIGURE C-10 (cont'd)

APPENDIX D

PROGRAM STRUCTURE

Each of the five programs consists of a main program and two small subroutines "TABLE" and "CROUT." "TABLE" generates geometrical and fluid parameters using the "PUNT" input. "CROUT" solves a system of linear simultaneous equations using the method of Prescott D. Crout. These two subroutines perform the same function in each program, but the form of the subroutines is not identical in all cases. Fortran IV format has been used throughout. No sense switches are used and each program will run without operator intervention and return to monitor control when completed. One input and one output tape are used and are labeled by the symbolic references "ITP1" and "ITP2", respectively. There are two cards in the beginning of each main program which define these symbols and are now set to 5 and 6. Sizes of the programs can be estimated from the knowledge that each fit comfortably on a 10,000-10 Decimal Digit Word IBM 7070. Until experience with the programs enables the user to make more accurate estimates, running times on a UNIVAC 1107 are estimated as follows:

Design Programs

Fuel Cell	$\sim$	7 min/100 designs
Isothermal	$\sim$	4 min/100 designs
Prim/Sec	$\sim$	5 min/100 designs

Performance Programs

a) Fuel Cell $\sim$12 seconds per segment calculation where the number of segment calculations equals:

$$\frac{S\ (S+1)}{2} - \frac{\left[(NS)\ (S)\right]\ \left[(NS)\ (S) - 1\right]}{2}$$

and where (S) is the total number of segments and (NS) (S) is the required number of operating segments to produce the proper outlet temperature. The maximum number of segment calculations is:

$$\frac{(S)\ \left[(S) + 1\right]}{2}$$

b) Isothermal (with segmentation) $\sim$ 8 seconds per segment calculation where the number of segment calculations equals:

$$\frac{S\ (S+3)}{2} - \frac{\left[(NS)\ \ (S)\right]\ \left[(NS)\ (S) + 1\right]}{2} + 1$$

The maximum number of segment calculations is: $\frac{(S)\ \left[(S) + 3\right]}{2}$

c) Isothermal (with proportional bypass) ~30 seconds per segment.

D-1. Design Program, H_2-H_2O Fuel Cell Direct Radiator-Condenser

A simplified flow chart (Figure D-1) for the fuel cell design program is given to aid the user in following the program and source deck printout (Figure D-2).

D-2. Design Program, Isothermal Direct Radiator-Condenser, with Subcooler

A simplified flow chart (Figure D-3) for the isothermal design program is given to aid the user in following the program and source deck printout (Figure D-4).

D-3. Design Program, Primary/Secondary Isothermal Direct Radiator-Condenser with Subcooler

A simplified flow chart (Figure D-5) for the primary/secondary design program is given to aid the user in following the program and source deck printout (Figure D-6).

D-4. Performance Analysis Program, H_2-H_2O Fuel Cell Direct Radiator-Condenser

A simplified flow chart (Figure D-7) for the fuel cell performance program is given to aid the user in following the program and source deck printout (Figure D-8).

D-5. Performance Analysis Program, Isothermal Direct Radiator-Condenser, with Subcooler

A simplified flow chart (Figure D-9) for the isothermal performance program is given to aid the user in following the program and source deck printout (Figure D-10).

COMPUTER FLOW CHART - FUEL CELL DESIGN PROGRAM

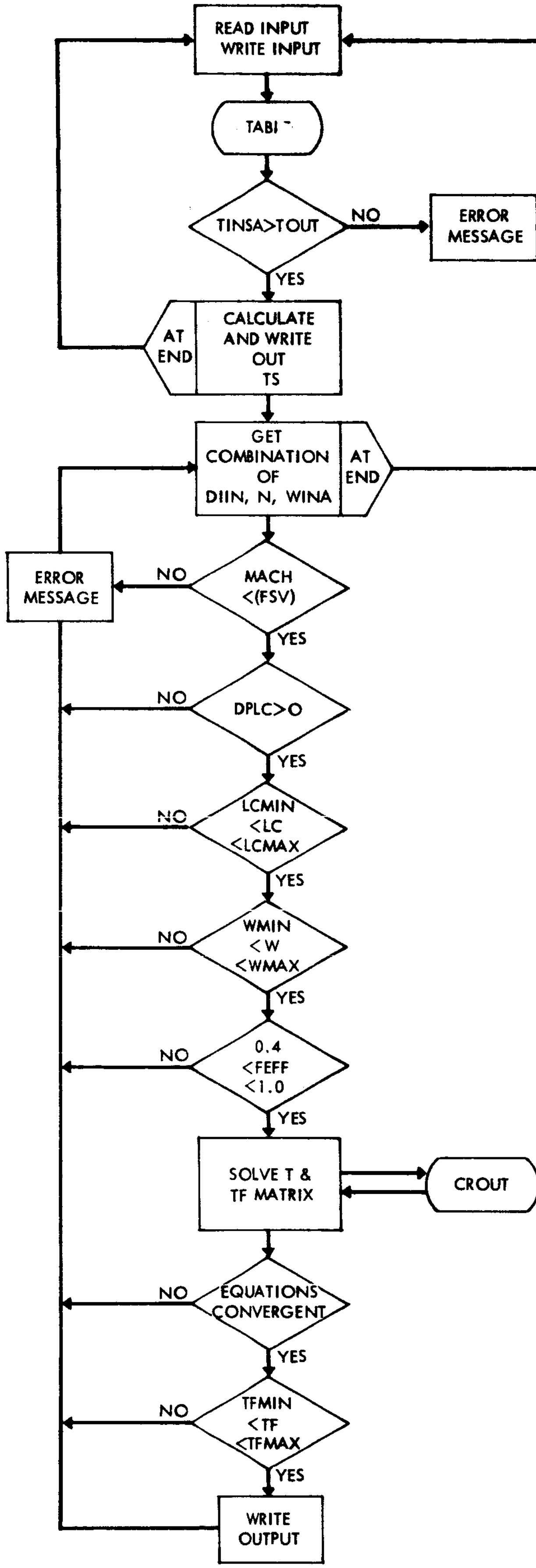

Figure D-1

SOURCE DECK PRINTOUT
FUEL CELL DESIGN PROGRAM

```
      DIMENSION D(34,33) , B(21) ,  C(21) ,ISB(6,21) ,T(21),RDC(21) ,
     1 EQCF(21,6),WW(5),TSIN(20),QQ(20,2),H(33),TITLE(16)
      COMMON C1,C2,C3,C4,C5,C6,C7,C8,C9,Z1,Z2,Z3,Z4,Z5,Z6,Z7,Z8,Z9,
     1 Y1,Y2,Y3, Y4 , ITP1,ITP2,D,H,J55,IJS
      EQUIVALENCE (WW(1),W1),(WW(2),W2),(WW(3),W3)
      FNSP (A,B)      = (A + B) / (2.*(A + B) +CON2)
C     THE NEXT 2 CARDS DEFINE TAPE UNITS ,FIRST INPUT,2ND OUTPUT
      ITP1 =  5
      ITP2 =  6
      ISL1=0
      ISL2=0
      DATA ISB/1,2,3,8,2*0,1,2,3,9,2*0,2,53,74,10,1,0,73,74,75,81,2*0,
     174,75,76,82,2*0,75,76,77,83,2*0,76,77,84,3*0,8,9,10,1,2*0,8,9,10,2
     2,16,0,9,60,81,3,8,17,80,81,82,74,88,0,81,82,83,75,89,0,82,83,84,76
     3,90,0,83,84,77,91,2*0,8,16,17,3*0,8,16,17,9,2*0,15,67,88,10,8,0,
     487,88,89,81,2*0,88,89,90,82,2*0,89,90,91,83,2*0,90,91,84,3*0/
  831 READ (ITP1,6776) TITLE
      WRITE (ITP2,6776) TITLE
 6776 FORMAT(16A5)
      READ           ( ITP1   ,   1003)NTS,(TSIN (I),QQ(I,1),QQ(I,2),I=
     1  1,NTS)
 1003 FORMAT(I2/(3F10.4))
 1002 FORMAT(8F10.4)
      READ           ( ITP1,1002)EMDG,EMDVIN,PM,TIN,TOUT,DPTOT,ZKTH,ZKF,
     1 RHOF,RHOT,RHOH,TH, ET,EF,FSV,DCMIN,DCMAJ,ELCMN ,ELCMX ,T1F,RHO1F,
     2 WMAX,WMIN,TEMIN,TEMAX,DNMIN,DNMAX,DNDEL,ENMIN,ENMAX,ENDEL ,WIMIN,
     3 WIMAX,WIDEL,TTG,TAU,ELNPO,EMEF,EMETH,ALPHS,ALPHT
      WRITE          (ITP2,8008)EMDG,EMDVIN,PM,TIN,TOUT,DPTOT,ZKTH,ZKF,
     1 RHOF,RHOT,RHOH,TH, ET,EF,FSV,DCMIN,DCMAJ,ELCMN ,ELCMX ,T1F,RHO1F,
     2 WMAX,WMIN,TEMIN,TEMAX,DNMIN,DNMAX,DNDEL,ENMIN,ENMAX
      WRITE (ITP2,5432)                                    ENDEL ,WIMIN,
     1 WIMAX,WIDEL,TTG,TAU,ELNPO,EMEF,EMETH,ALPHS,ALPHT
      TCG=TTG
 8008 FORMAT(50H DESIGN PROGRAM,H2 - H20 FUEL CELL , DIRECT R/C   /12H F
     1IXED INPUT79X3HMDG7X5HMDVIN10X2HPM9X3HTIN8X4HTOUT7X5HDPTOT9X3HKTH
     210X2HKF8X4HRHOF8X4HRHOT/5X7HLBS/MIN5X7HLBS/MIN8X4HPSIA7X5HDEG R7X5
     3HDEG R9X3HPSI3X9HB/HR FT F3X9HB/HR FT F3X9HLBS/CU FT3X9HLBS/CU FT/
     410F12.4//8X4HRHOH10X2HTH10X2HET10X2HEF9X3HFSV7X5HDCMIN7X5HDCMAJ7X5
     5HLCMIN7X5HLCMAX9X3HTIF/3X9HLBS/CU FT8X4HINCH46X2HFT10X2HFT10X2HFT1
     60X2HFT8X4HINCH/10F12.4//7X5HRHOIF8X4HWMAX8X4HWMIN7X5HTEMIN7X5HTEMA
     7X7X5HDIIN07X5HDIINF7X5HDIIND9X3HN 09X3HN F/4X8HLB/CU.FT10X2HFT10X2
     8HFT8X4HINCH8X4HINCH8X4HINCH8X4HINCH8X4HINCH/10F12.4/)
 5432 FORMAT( /,                                          7X3HN D5X6HWINA
     105X6HWINA F5X6HWINA D8X3HTTG8X3HTAU6X5H-LNPO8X3HMEF7X4HMETH6X5HALP
     2HS6X5HALPHT/17X4HINCH7X4HINCH7X4HINCH7X4HDAYS19X3HPSI8X3HP
     3SI/F10.0,6F11.4,2F11.0,2F11.4//)
      CALL TABLE
      IF(DNDEL)803,802,803
  802 DNDEL=999.
```

FIGURE D-2

```
 803   IF(ENDEL)805,804,805
 804   ENDEL=999.
 805   IF(WIDEL)807,806,807
 806   WIDEL=999.
 807   CONM = EMDG + EMDVIN
       I  = 1. +(DNMAX-DNMIN)/ DNDEL +.00001
       J  = 1. +(ENMAX-ENMIN)/ ENDEL +.00001
       K  = 1. +(WIMAX-WIMIN)/ WIDEL +.00001
       I=NTS*I*J*K
       WRITE           ( ITP2, 8009 ) I
 8009  FORMAT(/I3,29H INPUT COMBINATIONS REQUESTED//)
       T0315=TOUT+315.
       T0460 =TOUT-460.
       TI315=TIN+315.
       EM906 =    9.06 * EMDG
       C119  =   .0109 *C1
       C14 = 4. * C1
       Z3C7E = Z3 *C7 * ET   *(-1.495 E-10)
       Z2C2  = Z2 *C2
       Z4C5  = Z4 * C5 * (-.238E-10)
       C2ZK  = .85 * C2 * ZKTH
       C327  =  .002722 * C3
       EMDVE=      EM906   /(.1502E+7 * PM * EXP (-.02531*TOUT)-1.)
       EM776 = 776.* EMDG
       TMT = TIN - TOUT
       SHIN  = EMDVIN / EMDG
       PM144 =   144. * PM
       CON32 = (RHOT  * EMETH *EMETH)**(-.16666667)
       TOUT2 =   2. * TOUT
       CON33 =CON32/( RHOF *EMEF *EMEF)**(-.16666667)
       EXCON = EXP (-.01185 * 920.)
       DCMN3 = 37.7 * DCMIN
       DCMJ3 = 37.7 * DCMAJ
       Z65 = .5 *Z6
       Z7C9=      Z7*C9
       PIMIN = 3.14 * Z6 * DCMIN
       PIMAJ = 3.14 * Z6 * DCMAJ
       CON35 = (1.-C8) * 4.
       C812  = 12. * C8
       RHOTF = RHOIF * TIF * .0417
       TH2  = 2. *TH
       Z2EF = Z2 * EF
       CON53 = EXP (.0237 *T0460)
       CON54 = EXP (.0079 *(TOUT-1380.))
       FEFF = 0.
       IF(ELCMN  +WMIN + TEMAX) 7770,7771,7770
 7771  FEFF = .4
 7770  RMIN =(EM776      +  85.6 * EMDVIN) / CONM
       EMEM = EMDG + EMDVE
       PINSA = PM * EMDVIN /( EM906      +EMDVIN)
       TAVE  = .5*(TIN   + TOUT)
       TA315=TAVE+315.
       CON2 = RMIN * TIN
       RME  =(EM776          + EMDVE *85.6) / EMEM
       CON51 = (CONM/EMEM)** .75
       TINSA = 562. + 39.51 *ALOG (PINSA)
       WRITE            ( ITP2,7061)TINSA
 7061  FORMAT(10H TINSA IS   F10.1/)
```

FIGURE D-2 (cont'd)

```
      TIN46=TINSA-460.
      CNN79 =            (EXP (.0237*TIN46)- EXP (.0237*T0460))
      TNMTO=TINSA-TOUT
      ROMIN =   PM144   / CON2
      SOVV = 6.72 * SQRT ( CON2)
      ROME = PM144 /(RME *TOUT)
      TAVSA = .5*(TINSA + TOUT)
  172 FORMAT(32HSTOP-TINSA NOT GREATER THAN TOUT)
      IF(TNMTO        ) 171   ,  171  ,173
  171 WRITE           ( ITP2,172                    )
      GO TO 832
  173 TIMT = TIN- TINSA
      EMDVAV =  EM906     /(.1502E+7 *PM *EXP (-.02531*TAVSA)-1.)
      CON1 =       TIMT    / TNMTO
      BETA1 = 1. + .45 * CON1
      BETA2 = 1. + CON1
      CON50= FSV * SOVV
      EMMV = EMDG + EMDVAV
      RMAV =(EM776       + 85.6 * EMDVAV) / EMMV
      CON52=  (CONM/EMMV)**.75
      ROMAV= PM144 / (RMAV * TAVE)
      DO 1205 ITS = 1,NTS
      TS     = TSIN(ITS)
      QIS   = QQ(ITS,1)
      QIT   = QQ(ITS,2)
      IF(TS    )   305,304  ,304
  304 TS4 = TS * TS
      TS4 = TS4* TS4
      TS = TS4 ** .25
      GO TO 3059
  305 TS4 = 5.83E+8 *(QIS *ALPHS/ALPHT + QIT)
 3059 WRITE           ( ITP2, 4011 ) TS
 4011 FORMAT(/7H TS IS F10.1,6H DEG R//)
  306 DIIN = DNMIN
 1204 DN118  =  DIIN *11.8E+6
      EN = ENMIN
 1202 QTC1 = (BETA2 *EMDG *3.42   + BETA1 * EMDVIN) *60. /EN
C      THE 1.15 IN THE NEXT EQ. IS THE CORR. TO THE THEORET. HT.LOSS EQ.
      QTC2 = 1.15 * 106200. * EMDG * PM **(-1.112) / EN
      EN2 = EN *EN
      EN248 = EN2      * 248.
      DIINN = DIIN * EN
      D1HA = .5 * DIIN * SQRT (EN/Z1)
      CNN77=  D1HA*Z1*3080.
      D11NH= 1.414 * D1HA
      Z5N12 = .0833 * Z5 * EN
      EN545 = .00545 * EN * RHOT
      DIIN2  =  DIIN * DIINN
      DIN11  =  DIINN /.11
      DN283  =  DIINN /2.83E+4
      DIIN3  =  DIIN2 / 3.06
      VMIN =          CONM / (ROMIN * DIIN3 )
      ROV   = ROMIN * VMIN
      VME =         EMEM / (ROME * DIIN3)
      VMAV =          EMMV / (ROMAV * DIIN3 )
      RV    = ROME * VMF
      REEHA = RV    * D1HA * 11.8E+6 /T0315
      REAV = ROMAV *DIIN * VMAV * 11.8E+6 / TA315
```

FIGURE D-2 (cont'd)

```
        CON8 = EMDVIN - EMDVAV
        IF(REAV - 2000.) 232 , 232 ,  23
 23     IF(REAV-4000.) 2301,2302,2302
 2302   FRAV = .316/REAV**.25
        GO TO 231
 2301   FRAV = .00277 * REAV ** .322
        GO TO 231
 232    FRAV = 64. /REAV
 231    REAV =             CON8 / (DN283 *(683.- TAVSA))
        WEFAV =          VMAV *SQRT (ROMAV) * CON8 / DIN11
 26     IF(REAV - 200.) 261, 261 , 262
 261    IF(WEFAV- 3.   ) 263, 262 , 262
 262    PH1AV  = CON52
        GO TO 264
 263    DRAV = 12.93 * SQRT (CON8 * ROMAV *(683.-TAVSA)/(FRAV * REAV *
       1 (EMDVAV+EMDG) * TA315))
        IF(REAV - 2000.)  2631 , 2631  , 2632
 2631   PH1AV = ( 1. + DRAV) **4.
        GO TO 264
 2632   PH1AV = (.5 + SQRT (.25 + DRAV)) ** 4.75
 264    REE =  RV  * DIIN * 11.8E+6 /(TOUT + 315.)
        IF(VMIN - CON50) 5,5 ,4001
 4001   WRITE              ( ITP2 ,4002 ) DIIN.EN , VMIN
 4002   FORMAT(4HDIIN,F10.4,10X1HN,F10.4,10X4HVMINF10.5,12H GT FSV*SOVV)
        GO TO 1201
 5      IF(REEHA - 2000.) 1402 , 1402, 1403
 1402   FREH = 64. / REEHA
        GO TO 1404
 1403   IF(REEHA - 4000.) 1407 ,1408,1408
 1407   FREH = .00277 *REEHA **.322
        GO TO 1404
 1408   FREH = .316 /REEHA**.25
 1404   PH1EH = CON51
        RE1HA= ROV  * D1HA *11.8E+6 / TI315
        IF(RE1HA - 2000.) 702 , 702 , 703
 702    FR1H =  64. / RE1HA
        GO TO 704
 703    IF(RE1HA - 4000.) 7031 , 7032, 7032
 7031   FR1H = .00277 * RE1HA**.322
        GO TO 704
 7032   FR1H = 0.316 / RE1HA**.25
 704    WINA = WIMIN
 6      Z5W =  75 * WINA
        WINA2 =   2. * WINA
        CON36 = CON35 * EN  * WINA
        WBAR1 = .0833 * 75 * EN *(    WINA2+ DIIN) *PIMIN
 8      DP1H = FR1H    *ROV  *VMIN *WBAR1/CNN77
        WBARE = 75 * WBAR1 + PIMAJ
 15     DPEH =FREH* PH1EH*  RV  * VME *WBARE/CNN77
        CON6  = DP1H + DPEH - DPTOT
        DPLC = 1.08E-4 *( ROV  *VMIN -3.* RV   *VME) - CON6
        IF(DPLC)4003,4003,16
 4003   WRITE              ( ITP2,4004)DIIN,EN,WINA,DPLC
 4004   FORMAT(4HDIIN,F10.4,10X1HN,F10.4,6X4HWINA,F10.4,6X4HDPLC,F10.4,10H
       1  NEGATIVE)
        GO TO 1200
 16     ELC =  773. *DPLC * DIIN /(FRAV *ROMAV* VMAV * VMAV *PH1AV)
        IF(ELCMX) 271, 273 , 271
```

FIGURE D-2 (cont'd)

```
271    IF(ELC - ELCMN) 4005,4005,272
272    IF(ELCMX - ELC) 4005,4005,273
4005   WRITE              ( ITP2,4006)DIIN,EN,WINA ,ELC
4006   FORMAT(4HDIINF10.4,10X1HN ,F10.4,6X4HWINA,F10.4,6X4H ELC,F10.4,13H
      1 OUT OF RANGE)
       GO TO 1200
273    CON9  = ELC *  DIINN
       IF(TTG) 274 , 28  ,  274
274    TT = TTG
       TTX=TTG
       GO TO  30
28     AP = .262 * Z2  * CON9
       TT = 3.31  * (AP * TAU/ELNPO)**.25 * CON32
30     TT2 = 2. * TT
       DOIN = DIIN + TT2
       CON2 = Z5 * WINA
       CON3 = 18.85/EN
       CON4 = .5 * DOIN
       WIN = (CON3 * DCMIN - CON4)* Z6 + CON2
       WOUT= (CON3 * DCMAJ - CON4)* Z6 + CON2
       IF(WMAX ) 301, 303 , 301
301    CON6 = .0833 *EN *(2.* WIN + DOIN)
       IF(CON6 - WMIN) 4007,4007, 302
302    IF(WMAX - CON6) 4007,4007, 303
4007   WRITE              ( ITP2,4008)DIIN,EN,WINA, CON6
4008   FORMAT(4HDIINF10.4,10X1HNF10.4,6X4HWINAF10.4,6X1HW,F10.4,13H OUT O
      1F RANGE)
       GO TO 1200
303    QT=TNMTO*QTC1+QTC2*CNN79
       CON6 = WIN + WOUT
       CON7 = TAVSA * TAVSA
       CON7 = CON7 * CON7
       CON8 = Z2EF * ELC *(CON7 - TS4)
       CON9 = .2857E-9 * DOIN * CON8
       CON8 = 35.E+8 *(QT - CON9) / (CON6 * CON8)
       IF(CON8-FEFF) 4012,4012, 307
307    IF(1. - CON8) 4012,4012, 308
4012   WRITE              ( ITP2, 4013)DIIN,EN,WINA ,CON8
4013   FORMAT(4HDIINF10.4,10X1HNF10.4,6X4HWINAF10.4,6X4HFEFFF10.5,13H OUT
      1 OF RANGE)
       GO TO 1200
308    CON9 =(EMDVIN-EMDVE) / DIINN
       FNVE = VMF *(  RV/(12.1 *REE**.25) + CON9/(7.54*ELC)) * (CON9 *
      1 (683. - TOUT)) **(-.33333333)
       IF(C5-1.)  31 , 35  , 39
31     CON1 = 2. * DOIN / CON6
       F3SP = SQRT (.05 * CON1 +.0025) / (CON1 +.1) +  SQRT (3.803+ 1.95*
      1   CON1) / (CON1 + 3.9)
       F4SP = SQRT (.2   * CON1 +.04   ) / (CON1 +.4) +  SQRT (3.24 + 1.8 *
      1   CON1) / (CON1 + 3.6)
       F5SP = SQRT (.45 * CON1 +.2025) / (CON1 +.9) +  SQRT (2.403+ 1.55*
      1   CON1) / (CON1 + 3.1)
       F6SP = SQRT (.8   * CON1 +.64   ) / (CON1 +1.6)+  SQRT (1.44 + 1.2 *
      1   CON1) / (CON1 + 2.4)
       CON2 = CON6/ DOIN
       CON3 = 1. / (1. + 2.*CON2)
       F1SP = .6366 *(1. + CON2 * (1.- SQRT (1.+DOIN/CON6)) + .5  *
      1  ATAN ( SQRT (1. - CON3 * CON3) / CON3 )   )
```

FIGURE D-2 (cont'd)

```
      GO TO 40
35    IF(Z3) 351,39,351
351   CON1 = DOIN / WIN
      CON2 = CON1 * CON1
      F3SP = FNSP (.05*CON1,.0025)  + FNSP (1.95 *CON1,3.803)
      F4SP = FNSP (.2 *CON1,.04   )  + FNSP (1.8  *CON1,3.24 )
      F5SP = FNSP (.45*CON1,.2025)  + FNSP (1.55 *CON1,2.403)
      F6SP = FNSP (.8 *CON1,.64   )  + FNSP (1.2  *CON1,1.44 )
      F1SP = .3183 *( ATAN (1. + 4./CON1) + .2146)
      GO TO 40
39    F3SP  =1.
      F4SP  =1.
      F5SP  =1.
      F6SP  =1.
      F1SP = 1.
40    WW(1)=.83333 * WIN   +.16667 * WOUT
      WW(4)=.66667 * WIN   +.33333 * WOUT
      WW(2)=.5   * CON6
      WW(5)=.33333 * WIN   +.66667 * WOUT
      WW(3)=.16667 * WIN   +.83333 * WOUT
C     CALC.  EGCF  -RDC  - B
      CON3 = EF * ELC
      CON4 =              F1SP * DOIN * ELC   * Z3C7E
      CON5  = Z4C5 * CON3  * DOIN
      CON6  = Z2C2 * CON3
      DO 3010 I= 1,15,7
      J  = 1   + I / 7
      CON7  =   CON6  * WW(J)
      RDC(I) =   0.
      RDC(I+1) = CON4
      RDC(I+2) = CON5
      RDC(I+3) = -.95E-11   * CON7          * (C6 + F3SP)
      RDC(I+4) = -1.9E-11   * CON7          * (C6 + F4SP)
      RDC(I+5) = -2.85E-11  * CON7          * (C6 + F5SP)
3010  RDC(I+6) = -3.8 E-11  * CON7          * (C6 + F6SP)
      DO 3020 I= 1,21
3020  B(I) = TS4 * RDC(I)
      CON7 = ELC * ZKF
      CON8 = ZKF / ELC
      DMD = DOIN - DIIN
      DPD = DOIN + DIIN
      CON3 = .348 * DIIN * ELC  / (.024 + DMD /ZKTH)
      CON4 = C3   * CON3
      CON5 = C14 * CON3
      CON3 =               DMD *DPD * ZKTH /ELC
      CON9  = C22K * ELC * DMD/DPD
      CON6  =  C327 * CON3
      CON10 =  C119  * CON3
      CON11=.5*QTC1
      CON12=QTC2
      CON13 =   CON12 * CON53
      CON14 =   -EXCON * CON12
      CON20 =  - CON12 *CON54
      DO 3050I = 1,3
      J = 7 * I
      K = 4 + I/3
      CON1  = CON7/WW(I)
      CON2  = CON8*WW(K)
```

FIGURE D-2 (cont'd)

```
      EQCF(J,1) = .952 * CON1
      EQCF(J,3) = .00834  * CON2
      EQCF(J,2) = - EQCF(J,1) -  EQCF(J,3)
      EQCF(J-1,1) = 1.334 * CON1
      EQCF(J-1,3) =  EQCF(J,1)
      EQCF(J-1,4) = .00624 * CON2
      EQCF(J-1,2) = - EQCF(J-1,1) - EQCF(J-1,3) - EQCF(J-1,4)
      EQCF(J-2,1) = 2.22 * CON1
      EQCF(J-2,3) = EQCF(J-1,1)
      EQCF(J-2,4) = .00417 * CON2
      EQCF(J-2,2) = -EQCF(J-2,1) - EQCF(J-2,3) - EQCF(J-2,4)
      EQCF(J-3,1) =  6.67 * CON1
      EQCF(J-3,3) =  EQCF(J-2,1)
      EQCF(J-3,4) = .002085 * CON2
      EQCF(J-3,2) = -EQCF(J-3,1) -EQCF(J-3,3) - EQCF(J-3,4)
      EQCF(J-4,3) =  EQCF(J-3,1)
      EQCF(J-4,1) = CON9
      EQCF(J-4,4) = CON6
      EQCF(J-4,5) = CON4
      EQCF(J-4,2) = - EQCF(J-4,4) - EQCF(J-4,5) - EQCF(J-4,1)
      J = J - 5
      EQCF(J,1) = CON5
      EQCF(J,3) = 2. * CON9
      EQCF(J,4) = CON10
      EQCF(J,2) = - EQCF(J,1) - EQCF(J,3) - EQCF(J,4)
      J = J-1
      EQCF(J,2) = CON5
 3050 EQCF(J,3) = 2. * CON4
      EQCF(17,5)=.33333333*EQCF(17,5)
      B(17)  =  -EQCF(17,5) * TOUT2 + B(17)
      EQCF(16,1)=.33333333*EQCF(16,1)
      B(16)  =  -EQCF(16,1) * TOUT2 + B(16)
      EQCF(14,4) = EQCF(21,3)
      EQCF(14,2) = EQCF(14,2) - EQCF(14,4)
      EQCF(13,5) = EQCF(20,4)
      EQCF(12,5) = EQCF(19,4)
      EQCF(11,5) = EQCF(18,4)
      EQCF(10,6) = EQCF(17,4)
      EQCF(9,5)  = EQCF(16,4)
      DO 3060 J = 9,13
 3060 EQCF(J,2) = EQCF(J,2) - EQCF(J+7,4)
      EQCF(8,4) = CON11
      B(8) = B(8) + TOUT2 * CON11 * .33333333
      EQCF(8,1) = -.33333333 *CON11- CON5 - EQCF(8,3)
      EQCF(1,1) = -CON11 - CON5  -  EQCF(1,3)
      EQCF(1,4) = -CON11
      B(1) = B(1) -CON11 *2. * TINSA - CON12*EXP (.0237 *TIN46)
      EQCF(15,1) = CON11 * 1.3333333 - .33333333*(CON5+ EQCF(15,3))
      B(15)=B(15)+.66666667*TOUT*(2.*CON11+EQCF(15,2)+EQCF(15,3))+CON13
C     RADIATOR MATRIX WITH EXPONENTIAL UNKNOWNS AND MULTIPLIED UNKNOWNS
C     CONSTRUCT DERIVITIVE MATRIX D
C     21 EQUATIONS ,15TH UNKNOWN IS THICKNESS ,20 TEMPERATURE  UNKNOWNS
      INSR=1
      J55 = 0
      IF(ISL2)391,391,399
  391 T(15)=.01
      INSR=2
  392 T(1)=TINSA
```

FIGURE D-2 (cont'd)

```
      T(8) =  TAVSA
      SAVE=T(15)
      T(15)= .66666667 * TOUT + .33333333 * TAVSA
      DO 780 I=1,2
      T(I+1) = T(I) - 2.5
      T(I+8) = T(I+7)- 2.5
 780  T(I+15)= T(I+14)- 2.5
      DO 781 I=3,6
      T(I+1)=T(I)-10.
      T(I+8)=T(I+7)-10.
 781  T(I+15)=T(I+14)-10.
      T(15)=SAVE
 399  ISL2=0
 400  ISL1=0
      DO 401  J= 1,21
      C(J) = T(J) * T(J)  * T(J)
      DO 401 K=1,21
 401  D(K,J)=0.
      DO 410  K= 1,21
      TF = 4. * RDC(K) * C(K)
      D(22,K) =  B(K) - .25 *TF * T(K)
      D(15,K) =  0.
      DO 409 L1 = 1,6
      J =  ISR(L1,K)
      IF(J) 410, 410 , 402
 402  TH = 1.
      J70 = J-70
      IF(J70)404,404,403
 403  J=J70
      TH = T(15)
 404  IF(J-50)4041,4041,4042
 4042 J=J-50
      D(J,K)=TF+EQCF(K,2)-T(15)*EQCF(K,3)
      D(22,K)=D(22,K)-EQCF(K,2)*T(J)+EQCF(K,3)*T(15)*T(J)
      D(15,K)=D(15,K)-T(J)*EQCF(K,3)
      GO TO 409
 4041 ACR= TH  * EQCF(K,L1)
      IF(K-J)406  , 405 , 406
 405  D(J,K)  = ACR+TF
      GO TO 407
 406  D(J,K)  = ACR
 407  D(22,K) = D(22,K) - T(J) * ACR
      IF(TH - 1.) 408 , 409 , 408
 408  D(15,K) =  D(15,K)  + EQCF(K,L1)* T(J)
 409  CONTINUE
 410  CONTINUE
      CON15  = EXP (.01185 * T(1))
      CON16  = EXP (.01185 * T(8))
      CON17  =  CON14 * CON15
      CON18  =  CON17 * CON16
      CON19  = .01185 * CON18
      CON21 = EXP (.0158  *T(8))
      CON22 =  CON20 * CON21
      CON23 = .0158  * CON22
      D(22,1)=D(22,1) - CON18
      D(22,8)=D(22,8) + CON18-CON22
      D(1,1) = D(1,1) + CON19
      D(8,1) = D(8,1) + CON19
```

FIGURE D-2 (cont'd)

```
      D(1,8) = D(1,8) - CON19
      D(8,8) = D(8,8) - CON19 + CON23
      D(22,15)= D(22,15) + CON22
      D(8,15)= D(8,15) - CON23
      IJS=1
      CALL CROUT(21)
      GO TO (4112,6200),IJS
6200  J55=0
      GO TO (391,6201,4111),INSR
6201  INSR=3
      T(15)=.1
      GO TO 392
4111  WRITE              ( ITP2,4113)DIIN,EN,WINA
4113  FORMAT(5H DIINF9.4,10X1HNF10.4,6X4HWINAF10.4,41H 20 CYCLES,21 EQUA
     1TIONS NOT YET CONVERGED/)
      GO TO 1200
4112  IF(ABS (H(15))-.0001) 4114,4115,4115
4115  ISL1=1
4114  DO 415 K=1,21
      T(K) =  T(K) + H(K)
      IF(ABS (H(K)) - 1.     )  415,414,414
414   ISL1=1
415   CONTINUE
4116  IF(ISL1)44,44,400
44    T30 = .33333333 *(TOUT2 + T(8))
      TF   = T(15)
      IF(TF - TFMIN) 4009,4009, 4107
4107  IF(TFMAX) 4109,4108,4109
4109  IF(TFMAX - TF) 4009,4009, 4108
4009  WRITE              ( ITP2,4010)DIIN,EN,WINA , TF
4010  FORMAT(5H DIINF9.4,10X1HNF10.4,6X4HWINAF10.4,6X2HTF,F10.5,13H OUT
     1OF RANGE )
      GO TO 1200
4108  CON31 = 27C9     * TF
      ISL2=1
      TFKF = TF *ZKF
      PSA1 = 6.658E-7 * EXP (.02531 * T(1))
      PSA2 = 6.658E-7 * EXP (.02531 * T(8))
      PSA3 = 6.658E-7 * EXP (.02531 * T30 )
      EMDV1 =  EM906 /(PM/PSA1-1.)
      EMDV2 =  EM906 /(PM/PSA2-1.)
      EMDV3 =  EM906 /(PM/PSA3-1.)
      CON21 = EMDG + EMDV1
      CON22 = EMDG + EMDV2
      CON23 = EMDG + EMDV3
      RM1 = (EM776 + 85.6 *EMDV1 )/ CON21
      RM2 = (EM776 + 85.6 *EMDV2 )/ CON22
      RM3 = (EM776 + 85.6 *EMDV3 )/ CON23
      T1SH= T(1) + .8333333 * TIMT
      T2SH= T(8) + .5         * TIMT
      T3SH= T30 + .1666667 * TIMT
      ROM1 = PM144 /( RM1 * T1SH)
      ROM2 = PM144 /( RM2 * T2SH)
      ROM3 = PM144 /( RM3 * T3SH)
      VM1  =         CON21  / (ROM1 * DIIN3)
      VM2  =         CON22 / (ROM2 * DIIN3)
      VM3  =         CON23 / (ROM3 * DIIN3)
      RE1 = ROM1 * VM1 * DN118 / ( T1SH +315.)
```

FIGURE D-2 (cont'd)

```
      RE2 = ROM2 * VM2 * DN118 / ( T2SH +315.)
      RE3 = ROM3 * VM3 * DN118 / ( T3SH +315.)
      CON17 = EMDVIN - EMDV1
      CON18 = EMDVIN - EMDV2
      CON19 = EMDVIN - EMDV3
      WEF1  = VM1 * SQRT (ROM1) * CON17 / DIN11
      WEF2  = VM2 * SQRT (ROM2) * CON18 / DIN11
      WEF3  = VM3 * SQRT (ROM3) * CON19 / DIN11
      RF1 = CON17 / (DN283 * (683. - T(1)))
      RF2 = CON18 / (DN283 * (683. - T(8)))
      RF3 = CON19 / (DN283 * (683. - T30))
      IF(RE1 - 2000.) 72,72 , 722
72    FR1 = 64. / RE1
      GO TO 723
722   IF(RE1 - 4000.) 7201,7221,7221
7201  FR1 = .00277*RE1 **.322
      GO TO 723
7221  FR1 = .316/ RE1 ** .25
723   IF(RF1 - 200.) 724,724 ,726
724   IF(WEF1 - 3.)  725,725 ,726
725   DR1 = 12.93*SQRT ((CON17*(683.-T(1)) *ROM1)/(FR1*RE1*(EMDV1+EMDG)*
     1 (T1SH + 315.) ))
      IF(RE1 - 2000.)  7251 , 7251 , 7252
7251  PH11 = (1. + DR1) ** 4.
      GO TO 73
7252  PH11 =  (.5 + SQRT (.25 + DR1))** 4.75
      GO TO 73
726   PH11 =  (CONM/ CON21)**.75
73    IF(RE2 - 2000.)  731  ,731 ,732
731   FR2 = 64. / RE2
      GO TO 74
732   IF(RE2 - 4000.) 7321,7322,7322
7321  FR2 =  .00277 * RE2 ** .322
      GO TO 74
7322  FR2 =  .316/ RE2 ** .25
74    IF(RF2-200.) 741 , 741 , 743
741   IF(WEF2 - 3.)742 , 742 , 743
742   DR2=12.93*SQRT ((CON18*(683.-T(8))*ROM2)/(FR2*RE2*(EMDV2+EMDG)*
     1 (T2SH + 315.)))
      IF(RE2 -2000.) 7421, 7421 ,7422
7421  PH12 = (1. + DR2)** 4.
      GO TO 75
7422  PH12 =  (.5 + SQRT (.25 + DR2)) ** 4.75
      GO TO 75
743   PH12 = (  CONM/CON22)**.75
75    IF(RF3 - 2000.) 751,751,752
751   FR3 =  64. /RE3
      GO TO 76
752   IF(RE3 - 4000.) 7521,7522,7522
7521  FR3 = .00277 * RE3 **.322
      GO TO 76
7522  FR3 = .316 / RE3 ** .25
76    IF(RF3 - 200.) 761,761,763
761   IF(WEF3 - 3.) 762, 762,763
762   DR3 = 12.93 * SQRT ((CON19*(683.-T30)*ROM3)/(FR3*RE3*(EMDV3+EMDG)*
     1  ( T3SH  + 315.)))
      IF(RE3 - 2000.) 7621, 7621, 7622
7621  PH13 = (1. +DR3) ** 4.
```

FIGURE D-2 (cont'd)

```
      GO TO 77
7622  PH13 =  (.5 + SQRT  (.25 + DR3)) ** 4.75
      GO TO 77
763   PH13 = (CONM/CON23) **.75
77    DIINX = ((FR1 * PH11 * CON21 * CON21/ROM1 + FR2 *PH12 *CON22*CON22
     1 /ROM2 + FR3 * PH13 *CON23 *CON23 /ROM3)*(ELC/(EN248*DPLC)))**.2
      IF(TCG) 7701,7701,7702
7701  TTX = TT *((DIINX+TT2)/DIIN)**.25 - CON31 * CON33
7702  DOINX = DIINX + 2. * TTX
      WINX  = Z5W + Z65 * (DCMN3 /EN - DOINX)
      WBRIX = Z5N12 *(WINA2 + DOINX) + PIMIN
      WBREX = 75 * WBRIX  + PIMAJ
      WOUX = Z5W + Z65 *(DCMJ3 /EN - DOINX)
      EMT  = EN545 * (DOINX * DOINX - DIINX*DIINX) * FLC
      WPW  = WBRIX + WBREX
      ZZAPP = .5*CON35*EN*(WINX+WOUX)
      EMF  = .00347 * ELC * RHOF * TF *(C812 * WPW + ZZAPP)
      EM1F = ELC * RHOTF * WPW
      EMHS = .00545 * RHOH *WPW * TH2 *(TH2 + 2.* D1HA)
      EMCR = EMT + EMF + EM1F + EMHS
      ACR =  .5 * ELC * WPW
      SHOUT = EMDVE /EMDG
      QTOT = EN * QT
      DO 6100 I = 1,21
6100  C(I) =-T(I) * T(I) * T(I) * T(I)  + TS4
      QFTOT =  0.0
      CON22 = 52.6E+8 / (72 * EF * FLC)
      DO 6106  J = 1,3
      SUM =0.
      DO 6101  I = 4,7
      ISUB = (J-1) * 7  + I
6101  SUM = SUM + 2. * (RDC(ISUB) *  C(ISUB))
      GO TO (6103,6104,6105) , J
6103  FEF1 = -CON22 * SUM / ( W1 * C(3))
      GO TO 6106
6104  FEF2 = -CON22 * SUM / ( W2 * C(10))
      GO TO 6106
6105  FEF3 = -CON22 * SUM / ( W3 * C(17))
6106  QFTOT =  QFTOT + SUM   *EN
      QTTOT =   QTOT - QFTOT
      WRITE            ( ITP2, 1707) DIIN,EN,WINA,SHIN,VMIN,D11NH, D1HA,
     1 WBRIX,DP1H,EMDVE,SHOUT,VME,D11NH,D1HA ,WBREX,DPEH,DIINX,TTY,DOINX
     2,ELC,DPLC,WINX,WOUX,TF,T(1),T(8),T30,QTOT,QFTOT,QTTOT,FEF1,FEF2
      WRITE (ITP2,1708)
     1 FEF3,ENVE,EMT,EMF,EM1F,EMHS,EMCR,ACR
1707  FORMAT(/11X4HDIIN14X1HN11X4HWINA11X4HSHIN11X4HVMIN10X5HDIINH11X4HD
     11HA10X5HWBR1X/11X4HINCH26X4HINCH24X6HFT/SEC11X4HINCH11X4HINCH13X2H
     2FT/8F15.5/11X4HDPIH11X4HMDVE10X5HSHOUT12X3HVME10X5HDIEHF11X4HDEHA11
     30X5HWBARE 11X4HDPEH/12X3HPSI8X7HLBS/MIN24X6HFT/SEC11X4HINCH12X3HIN
     4.13X2HFT12X3HPSI/8F15.5/10X5HDIINX12X3HTTX10X5HDOINX13X2HLC11X4HDP
     5LC11X4HWINX11X4HWOUX13X2HTF/11X4HINCH11X4HINCH11X4HINCH13X2HFT12X3
     6HPSI11X4HINCH11X4HINCH11X4HINCH/8F15.5/12X3HT1012X3HT2012X3HT3011X
     74HQTOT10X5HQFTOT10X5HQTTOT11X4HFEF111X4HFEF2/3(10X5HDEG R),3(11X
     8 4HB/HR)/8F15.5 )
1708  FORMAT(                               11X4HFEF312X3HNUF13X2HMT13X2HMF1
     12X3HMIF12X3HMHS12X3HMCR12X3HACR/22X8HNO OF GS12X3HLBS12X3HLBS12X3H
     2LBS12X3HLBS12X3HLBS10X5HSQ FT/8F15.5//)
1200  WINA = WINA + WIDEL
```

FIGURE D-2 (cont'd)

```
         IF(WINA - WIMAX)  6 ,  6  , 1201
  1201   EN = EN + ENDEL
         IF(EN - ENMAX)  1202,1202 ,1203
  1203   DIIN = DIIN + DNDEL
         IF(DIIN - DNMAX)1204, 1204,1205
  1205   CONTINUE
  832    GO TO 831
         END
         SUBROUTINE TABLE
         DIMENSION CCC(9,3)  ,ZZZ(9,5) ,C(9) , Z(9 )
         COMMON C,Z,Y1,Y2,Y3, Y4 ,ITP1,ITP2
  C      CREATE RADIATOR INPUT TABLE
  C      PROGRAM CONSTANTS - SELECTION
         DATA CCC,ZZZ/3*1.,0,3*0.,0,1.,2*0.0,1.125,.5,.75,0.,2*1.,.82,1.,.25,
        1.75,1.,1.5,0.,2.,2*0.,1.,.5,5*1.,0.,1.,0.,1.,1.,.5,0.,2*1.,0.,.4.,2
        2*1.,1.5,3*.866,1.,0.,1.,0.,3.,2.,3*.707,1.,0.,1.,0.,4.,1.,.5,0.,1.
        3,0.,1.,4.,1.,1./
         CCC(4,1) = 0.5
         READ (ITP1,1002) I,J,K,L
  1002   FORMAT(4I1)
         WRITE            ( ITP2,1005)I,J,K,L
  1005   FORMAT(/8H PUNT IS 2X4I1/)
         DO  1    I1   = 1,9
         C(I1)   =   CCC(I1,I)
  1      Z(I1)   =   ZZZ(I1,J)
         GO TO (16,15,16,16,15),J
  15     Z(3) = C(4)
  16     CONTINUE
         IF(K-1) 2   ,   2    ,   3
  2      Y1 = 1.
         Y2 = 0.
         GO TO 4
  3      Y1 =  0.
         Y2 =  1.
  4      IF(L  - 1)   5 ,  5 ,  6
  5      Y3 = 1.
         Y4 = 0.
         RETURN
  6      Y3 = 0.
         Y4 = 1.
         RETURN
         END
```

FIGURE D-2 (cont'd)

```
      SUBROUTINE CROUT(N)
      DIMENSION H(33),A(34,33),SPACE(24)
      COMMON SPACE,A,H,J55,IJS
      N1=N+1
      DO 200 K=1,N
      K1=K+1
      J=K
      DO 100 I=K,N
      SUM=0.0
      IF(J-I)10,13,10
   10 IF(I-1)13,13,11
   11 IF(I-J)17,17,21
   17 ISMX=I-1
      DO 12 IS=1,ISMX
   12 SUM=SUM+A(IS,I)*A(I,IS)
   13 A(J,I)=A(J,I)-SUM
      GO TO 100
   21 JSMX=J-1
      DO 22 JS=1,JSMX
   22 SUM=SUM+A(JS,I)*A(J,JS)
   23 A(J,I)=A(J,I)-SUM
  100 CONTINUE
      I=K
      DO 200 J=K1,N1
      SUM=0.0
      IF(I-1)233,233,231
  231 ISMX=I-1
      DO 232 IS=1,ISMX
  232 SUM=SUM+A(IS,I)*A(J,IS)
  233 IF(A(I,I))350,351,350
  351 A(J,I)=0.0
      GO TO 200
  350 A(J,I)=(A(J,I)-SUM)*(1./A(I,I))
  200 CONTINUE
C     HAVE COMPLETED FINDING THE DERIVED MATRIX
      DO 300 IS=1,N
      SUM=0.0
      JS=N-IS+1
      JS1=JS+1
      DO 280 KS=JS1,N
      IF(KS-N)280,280,300
  280 SUM=SUM+A(KS,JS)*H(KS)
  300 H(JS)=A(N1,JS)-SUM
      J55=J55+1
      IF(20-J55) 302,302,303
  302 IJS=2
  303 RETURN
      END
```

FIGURE D-2 (cont'd)

COMPUTER FLOW CHART - ISOTHERMAL DESIGN PROGRAM

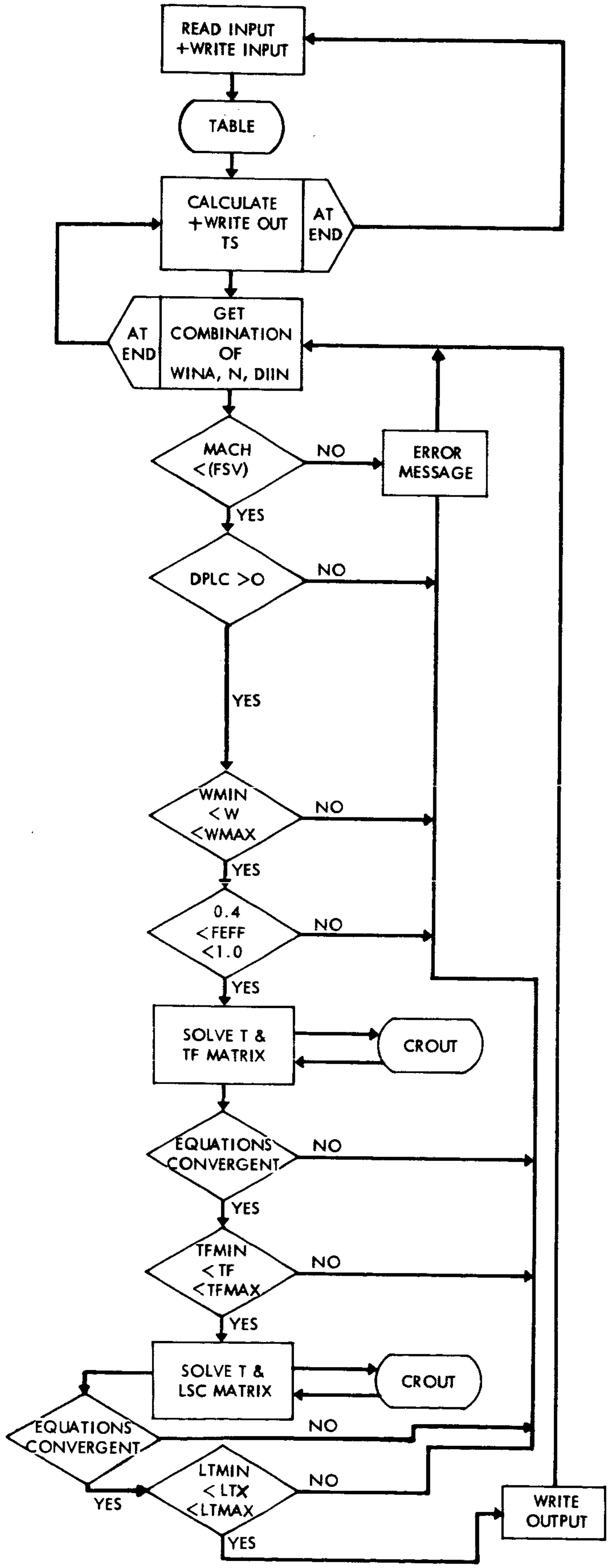

Figure D-3

SOURCE DECK PRINTOUT
ISOTHERMAL DESIGN PROGRAM

```
      DIMENSION T(14),DERIV(15,14),T3(14),ERROR(14),DELTA(14),CNST(14),
     1XTS(20),XQIS(20),XQIT(20),CON(9),TITLE(16)
      COMMON N,J55,IHALT,INDXS,ITP1,ITP2,DERIV,DELTA,C1,C2,C3,C4,C5,C6,
     1 C7, C8,C9,Z1,Z2,Z3,Z4,Z5,Z6,Z7,Z8,Z9,Y1,Y2,Y3,Y4
      ITP1 = 5
      ITP2 = 6
1     READ (ITP1,6776) TITLE
      WRITE (ITP2,6776) TITLE
6776  FORMAT(16A5)
      READ          ( ITP1,1000)INTS,(XTS(I),XQIS(I), XQIT(I),I=1,INTS)
1000  FORMAT(I2/,(3F10.4))
      READ          ( ITP1,1001)PC,TC,EMDT,XIN,DPTOT,TOUT,R,GAMMA,VISV,
     1VISL,HFG,CL,RHOL,SUFT,EKC,RHOT,RHOF,EKTH,EKF,RHOH,TH,FSV,ET,EF,
     2CV,TIN,TAU,ELNPO,EMEF,EMETH,TTG,ALPHS,ALPHT,DCMIN,DCMAJ,ELTMN,
     3ELTMX,TIF,RHOIF,WMIN,WMAX,TFMIN,TFMAX
     4,DMIN,DMAX,DDEL,ENMIN,ENMAX,ENDEL,WNMIN,WNMAX,WNDEL
1001  FORMAT(8F10.4)
      CALL TABLE
```

FIGURE D-4

```
      WRITE           ( ITP2,1002)PC,TC,EMDT,XIN,DPTOT,TOUT,R,GAMMA,VISV
     1,VISL,HFG,CL,RHOL,SUFT,EKC,RHOT,RHOF,EKTH,EKF,RHOH,TH,FSV,ET,EF,
     2CV,TIN,TAU,ELNPO,EMEF,EMETH
      WRITE (ITP2,8873)          TTG,ALPHS,ALPHT,DCMIN,DCMAJ,ELTMN,
     1ELTMX,TIF,RHOIF,WMIN,WMAX,TFMIN,TFMAX
     2,DMIN,DMAX,DDEL,ENMIN,ENMAX,ENDEL,WNMIN,WNMAX,WNDEL
1002  FORMAT(31H DESIGN PROGRAM  ISO  R/C  W/SC/,12H FIXED INPUT/,8X2HPC
     18X2HTC7X3HMDT7X3HXIN5X5HDPTOT6X4HTOUT9X1HR5X5HGAMMA6X4HVISV6X4HVIS
     2L/,6X4HPSIA5X5HDEG R3X7HLBS/MIN17X3HPSI5X5HDEG R6X4HFT/R11X9HLB/FT
     3 SEC1X9HLB/FT SEC/,8F10.4,2F10.8/
     4                           7X3HHFG8X2HCL6X4HRHOL6X4HSUFT8X2HKC6X4
     5HRHOT6X4HRHOF7X3HKTH8X2HKF6X4HRHOH/,6X4HB/LB4X6HB/LB F1X9HLBS/CU F
     6T4X6HLBS/FT1X9HB/HR FT F1X9HLBS/CU FT1X9HLBS/CU FT1X9HB/HR FT F1X9
     7HB/HR FT F1X9HLBS/CU FT/10F10.4/,8X2HTH7X3HFSV8X2HET8X2HEF8X2HCV7X
     83HTIN7X3HTAU5X5H-LNPO7X3HMEF6X4HMETH/,6X4HINCH34X6HB/LB F5X5HDEG R
     96X4HDAYS17X3HPSI7X3HPSI/,8F10.4,2F10.0)
8873  FORMAT                                   (7X3HTTG5X5HALPHS5X5HALPHT5
     1X5HDCMIN5X5HDCMAJ5X5HLTMIN5X5HLTMAX7X3HTIF5X5HRHOIF6X4HWMIN/,6X4HI
     2NCH28X2HFT8X2HFT8X2HFT8X2HFT6X4HINCH1X9HLBS/CU FT8X2HFT/,10F10.4/,
     36X4HWMAX5X5HTFMIN5X5HTFMAX6X4HDMIN6X4HDMAX6X4HDDEL6X4HNMIN6X4HNMAX
     46X4HNDEL3X7HWIN MIN3X7HWIN MAX3X7HWIN DEL/,8X2HFT6X4HINCH6X4HINCH6
     5X4HINCH6X4HINCH6X4HINCH36X4HINCH6X4HINCH6X4HINCH,/,12F10.4//)
      WNMAX=WNMAX-.00001
      ENMAX=ENMAX-.00001
      DMAX=DMAX-.00001
      ISL1 = 0
      IF(ELTMN) 551,551, 554
551   IF(WMIN)  552,552, 554
552   IF(TFMAX) 550,553, 554
553   FEFF = 0.4
      GO TO 560
554   FEFF = 0.0
560   ISL1 = 1
550   CON(8)=1.272 * C2
      PPWR = EMDT *DPTOT /  (236. * RHOL)
      WRITE (ITP2,9962) PPWR
9962  FORMAT(/8H PPWR IS F15.8,3H HP/)
      ST1 = R * TC
      ST59 = CL / EKC
      ST80 = Z6 / 2.0
      ST81 = 60.0 * EMDT
      RHOV = 144.0 * PC / ST1
      SOVV = 5.67 * SQRT (ST1 * GAMMA)
      ST10 = TOUT * TOUT * TOUT
      RAT = 3.0 * ST10 * HFG / (TC*CL*(TC*TC*TC - ST10))
      ST30 = 16.0 * VISL * RHOV / (XIN * VISV * RHOL)
      DO 95  LOOP1 = 1,INTS
      TS = XTS(LOOP1)
      Q1S = XQIS(LOOP1)
      Q1T = XQIT(LOOP1)
      DIIN = DMIN
      IF(TS) 55, 54, 54
54    TS4 = TS * TS * TS * TS
      GO TO 7887
55    TS4 = 5.83E+08 * (Q1S * ALPHS / ALPHT + Q1T)
7887  TS =  TS4 ** .25
      WRITE (ITP2,9961) TS
9961  FORMAT(/7H TS IS F10.1,6H DEG R///)
```

FIGURE D-4 (cont'd)

```
2      ST11 = 0.5 * DIIN
       ST58 = EKC / DIIN
       EN = ENMIN
3      WINA = WNMIN
       CON(9)=20.0 * EMDT * CL / EN
       ST56 = EN * DIIN
       VIN = 3.06 * EMDT * XIN / (RHOV * DIIN * ST56)
       IF(VIN - FSV * SOVV) 4, 4, 5
5      WRITE(ITP2,2005) DIIN,EN,VIN
2005   FORMAT(5H DIINF10.5,5X1HNF14.5,5X5HVINF12.5,5X    24HGREATER THAN
      1 FSV * SOVV )
       GO TO 91
4      DIHA = 0.5 * DIIN * SQRT (EN / ZI)
       ST6 = RHOV * VIN / (12.0 * VISV)
       REVIN = ST6 * DIIN
       IF(VISV*REVIN/VISL-2300.0) 571,571,572
571    HSC = 115.0 * Y3 * ST58 * (EMDT*ST59/( ST56  ))**0.4  +
      1 60.0 * Y4 * ST58
       GO TO 573
572    HSC = 115.0 * Y3 * ST58 * (EMDT*ST59/( ST56  ))**0.4  +
      1 1.07 *Y4*ST58*(EMDT/(ST56 * VISL ))**0.8 *(VISL*ST59)**0.3
573    CONTINUE
       REIHA = ST6 * DIHA
       ST7 = RHOV * VIN * VIN
       WIN = Z6 * (18.85 * DCMIN / EN - ST11)
       WOUT = Z6 * (18.85 * DCMAJ / EN - ST11)
       ST13 = (WIN - RAT * WOUT) / (WIN + WOUT)
       CSC = Z5 * RAT + Z6 *(SQRT (ST13 * ST13 + RAT) -  ST13)
       WIF = (WIN + WOUT * CSC) / (1.0 + CSC)
       ST16 = (WIN - WIF) / (WIN + WIF)
       ST15 = WIN / (WIN + WIF)
       EKK1 = Z5 * 0.833 + Z6 * (1.0 - 1.666 * ST15 + 0.695 * ST16)
       EKK2 = Z5 * 0.5 + Z6 * (1.0 - ST15 + 0.25 * ST16)
       EKK3 = Z5 * 0.167 + Z6 * (1.0 - 0.333 * ST15 + 0.0279 * ST16)
       REV1 = EKK1 * REVIN
       REV2 = EKK2 * REVIN
       REV3 = EKK3 * REVIN
       IF(REV1-2000.0) 210, 210, 211
210    FR1 = 64.0/REV1
       GO TO 22
211    IF(REV1-4000.0) 212, 213, 213
212    FR1 = 0.00277 * REV1 ** 0.322
       GO TO 22
213    FR1 = 0.316 / REV1 ** 0.25
22     IF(REV2-2000.0) 220, 220, 221
220    FR2 = 64.0/REV2
       GO TO 23
221    IF(REV2-4000.0) 222, 223, 223
222    FR2 = 0.00277 * REV2 ** 0.322
       GO TO 23
223    FR2 = 0.316 / REV2 ** 0.25
23     IF(REV3-2000.0) 230, 230, 231
230    FR3 = 64.0/REV3
       GO TO 24
231    IF(REV3-4000.0) 232, 233, 233
232    FR3 = 0.00277 * REV3 ** 0.322
       GO TO 24
233    FR3 = 0.316 / REV3 ** 0.25
```

FIGURE D-4 (cont'd)

```
24     ST23 = 0.00395 * SQRT (RHOV / RHOL) * EMDT * VIN / (SUFT*ST56)
       ST24 = 1.0 - EKK1 * XIN
       WEF1 = EKK1 * ST23 * ST24
       ST25 = 1.0 - EKK2 * XIN
       WEF2 = EKK2 * ST23 * ST25
       ST26 = 1.0 - EKK3 * XIN
       WEF3 = EKK3 * ST23 * ST26
       ST27 = 0.1275 * EMDT / (ST56 * VISL)
       RF1 = ST27 * ST24
       RF2 = ST27 * ST25
       RF3 = ST27 * ST26
       HCOND=2.75*SQRT (CL*RHOL*RHOV*EKC*FR2/VISL)*VIN*Y1*Y4*.5 +
      1 (5000. *Y2 + 2000. *Y1*Y3) / EKK2
       IF(WEF1 - 3.0) 30, 30, 302
30     IF(RF1 - 200.0) 301, 301, 302
301    DR1 = SQRT (ST24 * ST30 / (FR1 * REV1 * EKK1))
       IF(REV1-2000.)3011,3011,3012
3011   PH11 = (1.0 + DR1 ) ** 4.0
       GO TO 303
3012   PH11 = (0.5 + SQRT (0.25 + DR1 )) ** 4.75
       GO TO 303
302    PH11 = (EKK1 * XIN) **(-.75)
303    IF(WEF2 - 3.0) 31, 31, 312
31     IF(RF2 - 200.0) 311, 311, 312
311    DR2 = SQRT (ST25 * ST30 / (FR2 * REV2 * EKK2))
       IF(REV2-2000.)3111,3111,3112
3111   PH12 = (1.0 + DR2 ) ** 4.0
       GO TO 313
3112   PH12 = (0.5 + SQRT (0.25 + DR2 )) ** 4.75
       GO TO 313
312    PH12 = (EKK2 * XIN) **(-.75)
313    IF(WEF3 - 3.0) 32, 32, 322
32     IF(RF3 - 200.0) 321, 321, 322
321    DR3 = SQRT (ST26 * ST30 / (FR3 * REV3 * EKK3))
       IF(REV3-2000.)3211,3211,3212
3211   PH13 = (1.0 + DR3 ) ** 4.0
       GO TO 323
3212   PH13 = (0.5 + SQRT (0.25 + DR3 )) ** 4.75
       GO TO 323
322    PH13 = (EKK3 * XIN) **(-.75)
323    CONTINUE
38     WBAR1 = 0.0833 * Z5 * EN * (2.0 * WINA + DIIN) + 3.14 * DCMIN * Z6
       DPIH = 0.000103 * ST7 * WBAR1 / (REIHA ** 0.25 * DIHA * Z1)
       DPLC = DPTOT - DPIH + ST7 / 9260.0
       IF(DPLC) 7,7,8
7      WRITE(ITP2,2004) DIIN,EN,WINA,DPLC
2004   FORMAT(5H DIINF10.5,5X1HNF14.5,5X4HWINAF11.5,5X
      14HDPLC,F11.5,5X,8HNEGATIVE)
       GO TO 89
8      ELC = DPLC * DIIN * 2320.0 / (ST7 * (PH11 * FR1 * EKK1 * EKK1 +
      1PH12 * FR2 * EKK2 * EKK2 + PH13 * FR3 * EKK3 * EKK3) )
       ELSC = ELC / CSC
       ELT=ELC+ELSC
       AP= 0.261 * Z2 *ST56 *ELT
       IF(TTG) 37, 37, 361
361    TT = TTG
       TTX = TTG
       GO TO 371
```

FIGURE D-4 (cont'd)

```
37     TT = 3.31 * (AP * TAU / ELNPO) ** 0.25 / (RHOT*EMETH*EMETH)**.16662200
371    DOIN = DIIN + 2.0 * TT                                           2201
       QTUB=0.2857E-09*Z2*EF*DOIN*EN*ELC*(TC*TC*TC*TC-TS4)              2202
       ST40 = DOIN / 2.0                                                2203
       FACT1 = DIIN * ELC                                               2204
       FACT2 = 1.0 / (24.0 / (HCOND * EKK2) + (DOIN - DIIN) / EKTH )    2205
       FACT3 = (DOIN - DIIN) / (DOIN + DIIN)                            2206
       FACT4 = EKTH * ELC                                               2207
       FACT5 = DOIN * ELC                                               2208
       FACT8 = FACT1 * FACT2                                            2209
       FACT9 = FACT3 * FACT4                                            2210
       CNST(1)  = 1.394 * C1 * FACT8 * TC + 1.495E-10 * Z3 * C7 * FACT5 2211
      1 * ET * TS4                                                      2212
       CNST(2)  = 0.348 * C3 * FACT8 * TC + 0.238E-10 * Z4 * C5 * FACT5 2213
      1 * EF * TS4                                                      2214
       CNST(7)  = 20.0 * EMDT / EN * (XIN * HFG + CV * (TIN - TC) )     2215
      1 - 0.697 * FACT8 * TC * (2.0 * C1 + C3)                          2216
       TRM1 = + 1.394 * C1 * FACT8 + 1.7 * C2 * FACT9                   2217
       TRM2 = 1.7 * C2 * FACT9                                          2218
       TRM4 = + 0.348 * C3 * FACT8 + 0.85 * FACT9 * C2                  2220     *
       TRM6 = +0.238E-10 * Z4 * C5 * EF * FACT5                         2221
       TRM12 = 0.697 * FACT8                                            2222
       CON(1)=DIIN / (24.0 / HSC + (DOIN - DIIN) / EKTH )               2223
       CON(2)=C2 * EKTH * (DOIN - DIIN) / (DOIN + DIIN)                 2224
       ENUE = 432.0 * (1.435E-04 * ST7 - DPLC) / (RHOL * ELC)           2225
       ST39 = Z5 * WINA                                                 2226
       WINX = ST39 + Z6 * (18.85 * DCMIN / EN - ST40)                   2227
       WOUX = ST39 + Z6 * (18.85 * DCMAJ / EN  - ST40)                  2228
       IF(WMAX) 41, 41, 40                                              2229
40     STORE = 0.0833 * EN * ( 2.0 * WINX + DOIN)                       2230
       IF(STORE-WMIN) 402, 401, 401                                     2231
401    IF(WMAX - STORE) 402, 41, 41                                     2232
402    WRITE(ITP2,2002) DIIN,EN,WINA,STORE                              2233
2002   FORMAT(5H DIINF10.5,5X1HNF14.5,5X4HWINAF11.5,5X
      11HW,F14.5,5X,12HOUT OF RANGE )                                   2235
       GO TO 89                                                         2236
41     WIFX = (WINX + WOUX * CSC) / (1.0 + CSC)                         2237
       IF(C5) 46, 42, 46                                                2238
42     ST42 = DOIN / (WINX + WIFX)                                      2239
       STORE=(WINX+WOUX)/DOIN                                                    *
       F1SP = 1.0 + 2.0 * STORE                                         2241     *
       F1SP = ATAN (SQRT (F1SP*F1SP-1.0)) / 2.0                         2242
       F1SP=0.6366*(1.+STORE*(1.-SQRT (1./STORE+1.)) + F1SP)                     *
       F3SP = SQRT (0.1 * ST42 + 0.0025) / (2.0 * ST42 + 0.1)  +  SQRT  2244     *
      1 (3.803 + 3.9 * ST42) / (2.0 * ST42 + 3.9)                       2245
       F4SP = SQRT (0.4 * ST42 + 0.04) / (2.0 * ST42 + 0.4)  +  SQRT    2246
      1 (3.24 + 3.6 * ST42) / (2.0 * ST42 + 3.6)                        2247
       F5SP = SQRT (0.9 * ST42 + 0.2025) / (2.0 * ST42 + 0.9) + SQRT    2248
      1 (2.403 + 3.1 * ST42) / (2.0 * ST42 + 3.1)                       2249
       F6SP = SQRT (1.6 * ST42 + 0.64) / (2.0 * ST42 + 1.6)  + SQRT     2250
      1 (1.44 + 2.4 * ST42) / (2.0 * ST42 + 2.4)                        2251
46     IF(C5 - 1.0) 50, 461, 50                                         2252
461    IF(Z3) 47, 50, 47                                                2253
47     ST46 = DOIN / WINX                                               2254
       F1SP=0.3183*(0.2148+ATAN (4.*WINX/DOIN +1.))                              *
       ST47 = ST46 * ST46                                               2256     *
       F3SP =(0.05 * ST46 + 0.0025) / (0.1 * ST46 + 0.005 + ST47)  +    2257
      1 (3.803 + 1.95 * ST46) / (7.606 + 3.9 * ST46 + ST47)             2258
```

FIGURE D-4 (cont'd)

```
      F4SP=(.2*ST46+.04)/(.4*ST46+.08+ST47)+
     1 (3.24 + 1.8 * ST46)  / (6.48 + 3.6 * ST46 + ST47)
      F5SP = (0.45 * ST46 + 0.2025) / (0.9 * ST46 + 0.405 + ST47) +
     1 (2.403 + 1.55 * ST46) / (4.806 + 3.1 * ST46 + ST47)
      F6SP = (0.8 * ST46 + 0.64) / (1.6 * ST46 + 1.28 + ST47) +
     1 (1.44 + 1.2 * ST46) / (2.88 + 2.4 * ST46 + ST47)
50    IF(C5 - 2.0) 51, 512, 51
51    IF(C5 - 1.0) 52, 511, 52
511   IF(Z3) 52, 512, 52
512   F3SP = 1.0
      F1SP = 1.0
      F4SP = 1.0
      F5SP = 1.0
      F6SP = 1.0
52    W2 = (WINX + WIFX) / 2.0
      IF(ISL1)56,56,555
555   ST55 = (2.1E+11 * EMDT * (XIN * HFG + CV * (TIN - TC)) - QTUB) /
     1((     WINX+WOUX)*ELC*EF*Z2*EN*(TC*TC*TC*TC-TS4))
      IF(ST55 - 1.0) 556, 557, 557
556   IF(FEFF - ST55) 56, 56, 557
557   WRITE(ITP2,2001) DIIN,EN,WINA,ST55
2001  FORMAT(5H DIINF10.5,5X1HNF14.5,5X4HWINAF11.5,5X
     14HFEFF,F11.5,5X,12HOUT OF RANGE  )
      GO TO 89
56    FACT6 = ELC * EKF / W2
      FACT7 = Z2 * C2 * EF * ELC * W2
      TRM3= 1.495E-10 *Z3 *C7 *FACT5 *ET *F1SP
      STORE = FACT7 * TS4
      CNST(3)  = 0.95E-11 * STORE * (C6 + F3SP)
      CNST(4)  = 1.9E-11 * STORE * (C6 + F4SP)
      CNST(5)  = 2.85E-11 * STORE * (C6 + F5SP)
      CNST(6)  = 3.8E-11 * STORE * (C6 + F6SP)
      TRM5 = 6.67 * FACT6
      TRM7 = +0.95E-11 * FACT7 * (C6 + F3SP)
      TRM8 = +1.9E-11 * FACT7 * (C6 + F4SP)
      TRM9 = +2.85E-11 * FACT7 * (C6 + F5SP)
      TRM10 = 0.952 * FACT6
      TRM11 = +3.8E-11 * FACT7 * (C6 + F6SP)
      N = 7
      T(7)=.01
      INSR=2
      GO TO 98
6741  T(7)=.1
      INSR=3
      GO TO 98
6743  T(7)=.001
      INSR=4
98    T(1)=TC-10.
      T(2)=T(1)-5.
      DO 99 I=3,6
99    T(I)=T(I-1)-30.
      J55=0
      DO 100 I=1,7
      T3(I) = T(I) * T(I) * T(I)
      DO 100 J =1,7
100   DERIV(J,I) = 0.0
11111 INDXS = 1
      DERIV(1,1) = -TRM1 - 4.0 * TRM3 * T3(1)
```

FIGURE D-4 (cont'd)

```
      DERIV(2,1) = TRM2
      DERIV(1,2) = DERIV(2,1) / 2.0
      DERIV(2,2) = -TRM4 - TRM5 * T(7) - 4.0 * TRM6 * T3(2)
      DERIV(3,2) = TRM5 * T(7)
      DERIV(7,2) = TRM5 * ( T(3) - T(2) )
      STORE = FACT6 * T(7)
      DERIV(2,3) = 6.67 * STORE
      DERIV(3,3) = -8.89* STORE - 4.0 * TRM7 * T3(3)
      DERIV(4,3) = 2.22 * STORE
      DERIV(7,3) = (6.67 * T(2) - 8.89* T(3) + 2.22 * T(4)) * FACT6
      DERIV(3,4) = DERIV(4,3)
      DERIV(4,4) = -3.554 * STORE - 4.0 * TRM8 * T3(4)
      DERIV(5,4) = 1.334 * STORE
      DERIV(7,4) = (2.22 * T(3) - 3.554 * T(4) + 1.334 * T(5) ) * FACT6
      DERIV(4,5) = DERIV(5,4)
      DERIV(5,5) = -2.286 * STORE - 4.0 * TRM9 * T3(5)
      DERIV(6,5) = 0.952 * STORE
      DERIV(7,5) = (1.334 * T(4) - 2.286 * T(5) + 0.952 * T(6) ) * FACT6
      DERIV(5,6) = TRM10 * T(7)
      DERIV(6,6) = -TRM10 * T(7) - 4.0 * TRM11 * T3(6)
      DERIV(7,6) = TRM10 * (T(5) - T(6))
      DERIV(1,7) = 2.0 * C1 * TRM12
      DERIV(2,7) = C3 * TRM12
      ERROR(1) = CNST(1) - TRM1 * T(1) + TRM2 * T(2) - TRM3 * T3(1)*T(1)
      ERROR(2) = CNST(2) - TRM4 * T(2) + TRM5 * T(7) * (T(3) - T(2))
     1 - TRM6 * T3(2) * T(2)  + TRM2 * T(1) / 2.0
      ERROR(3) = CNST(3) + T(7) * FACT6 * (6.67 * T(2) - 8.89* T(3) +
     1 2.22 * T(4)) - TRM7 * T3(3) * T(3)
      ERROR(4) = CNST(4) + T(7) * FACT6 * (2.22 * T(3) - 3.554 * T(4)+
     1 1.334 * T(5)) - TRM8 * T3(4) * T(4)
      ERROR(5) = CNST(5) + T(7) * FACT6 * (1.334 * T(4) -2.286 * T(5)+
     1 0.952 * T(6)) - TRM9 * T3(5) * T(5)
      ERROR(6) = CNST(6) + TRM10 * T(7) * (T(5) - T(6)) - TRM11 * T3(6)
     1 * T(6)
      ERROR(7) = CNST(7) + TRM12 * (2.0 * C1 * T(1) + C3 * T(2))
      WRITE (ITP2,8765) ERROR(7),CNST(7),TRM12                          *N
      DO 701 I = 1,N
701   DERIV(N+1,I) =-ERROR(I)
      CALL CROUT
      GO TO (14,6742),INDXS
6742  GO TO (6741,6741,6743,10),INSR
10    WRITE(ITP2,2000) DIIN,EN,WINA
2000  FORMAT(5H DIIN,F10.5,5X1HNF14.5,5X4HWINAF11.5,5H
     1 SUBCONDENSER EQUATIONS NONCONVERGENT AFTER 20 TRIES     )
      GO TO 89
6000  GO TO 11111
14    DO 101 I = 1,7
      T(I) = T(I) + DELTA(I)
      T3(I) = T(I) * T(I) * T(I)
      DO 101 J =1,7
101   DERIV(J,I) = 0.0
      IF(ABS (DELTA(7))-.0001)800,6000,6000
800   DO 801 I = 1,6
      IF(ABS(DELTA(I))   -1.)801,6000,6000
801   CONTINUE
106   TF = T(7)
      IF(TFMAX + TFMIN) 110, 109, 110
110   IF(TFMAX-TF) 108, 107, 107
```

FIGURE D-4 (cont'd)

```
107    IF(TF-TFMIN) 108, 109, 109                                          2373
108    WRITE(ITP2,2006) DIIN,EN,WINA,TF                                    2374
2006   FORMAT(5H DIINF10.5,5X1HNF14.5,5X4HWINAF11.5,5X
      12HTF,F13.5,5X,12HOUT OF RANGE )                                     2376
       GO TO 89                                                            2377
109    QTOTC = ST81 *(XIN * HFG + CV * (TIN - TC))
       QTTC =(4.485E-10 * F1SP *Z3 * C7 * FACT5 *ET *(T3(1)*T(1)
      1 - TS4) + 1.428E-10 * Z4 * C5 * EF * FACT5  * (T3(2)*T(2)
      2 - TS4))*EN
       QFTC = QTOTC - QTTC
       FEFC = 17.5E+08 * QFTC / (EN * ELC * EF * Z2 * W2 *                 2379
      1 ( T(2)*T(2)*T(2)*T(2) - TS4)  )                                    2380
       W4 = (3.0 * WIFX + WOUX) / 4.0                                      2381
       W45 = (WIFX + WOUX) / 2.0                                           2382
       WRITE (ITP2,8765) T,DELTA,ERROR,HCOND,F1SP                                *N
8765   FORMAT(/7E15.8)                                                           *N
       W5 = (3.0 * WOUX + WIFX) / 4.0                                      2383
61     IF(Z6 - 1.0) 65, 611, 65                                            2384
611    ST61 = DOIN / W45                                                   2385
       STORE = (WIN+WOUT)/DOIN                                             2386
       FS1SP = 1.0 + 2.0*STORE                                             2387
       FS1SP = ATAN (SQRT (FS1SP*FS1SP-1.0))/2.0                           2388
       FS1SP=.6366*(1.+STORE*(1.-SQRT (1./STORE+1.)) + FS1SP)                    *N
       FS3SP = SQRT (0.05 * ST61 + 0.0025) / (ST61 + 0.1)  + SQRT          2390  **
      1 (3.803 + 1.95 * ST61) / (ST61 + 3.9)                               2391
       FS4SP = SQRT (0.2 * ST61 + 0.04) / (ST61 + 0.4)  +  SQRT            2392
      1 (3.24 + 1.8 * ST61)  / (ST61 + 3.6)                                2393
       FS5SP = SQRT (0.45 * ST61 + 0.2025) / (ST61 + 0.9) + SQRT           2394
      1 (2.403 + 1.55 * ST61) / (ST61 + 3.1)                               2395
       FS6SP = SQRT (0.8 * ST61 + 0.64) / (ST61 + 1.6) +  SQRT             2396
      1 (1.44 + 1.2 * ST61) / (ST61 + 2.4)                                 2397
       GO TO 66                                                            2398
65     FS3SP = F3SP                                                        2399
       FS1SP = F1SP                                                        2400
       FS4SP = F4SP                                                        2401
       FS5SP = F5SP                                                        2402
       FS6SP = F6SP                                                        2403
66     T(14)=1.2*ELSC                                                      2404
       ZAP=.4*(TC-TOUT)                                                    2405
       T(1)=TC-ZAP                                                         2406
       DO 7000 I=1,6                                                       2407
       T(I+1)=T(I)-ZAP                                                     2408
7000   T(I+7)=T(I+1)-ZAP                                                   2409
       INSR=1                                                              2410
7003   J55=0                                                               2411
       DO 201 I = 1,13                                                     2412
       ZAP=I                                                               2413
       IF(INSR-1)7002,7001,7002                                            2414
7002   T(I)=TC-5.*ZAP                                                      2415
7001   T3(I)=T(I)*T(I)*T(I)                                                2416
       CNST(I) = 0.0                                                       2417
       DO 201 J = 1,15                                                     2418
       DERIV(J,14)=0.0                                                           *N
201    DERIV(J,I) = 0.0                                                    2419
       CNST(1)      = CON(9) * (3.0 * TC - TOUT)                           2420
       CNST(8)      = -2.0 * CON(9) * TOUT                                 2421
       CON(3)=TF * EKF / W4                                                2422
       CON(4)=Z2 * C2 * EF * W4                                            2423
```

FIGURE D-4 (cont'd)

```
      CON(5)=TF * EKF / W5
      CON(6)=Z2 * C2 * EF * W5
      CON(7) = Z2 * C2 * EF * W5
      TRM13  =              CON(1) * (2.092 * C1 + 1.046 * C3)
      TRM14 = 1.122E-10 * Z3 * C7 * ET * DOIN * FS1SP
      TRM15 = 0.357E-10 * Z4 * C5 * EF * DOIN
      TRM16 = 0.1428E-10 * CON(4) * (C6 + FS3SP)
      TRM17 = 0.285E-10 * CON(4) * (C6 + FS4SP)
      TRM18 = 0.428E-10 * CON(4) * (C6 + FS5SP)
      TRM19 = 0.57E-10 * CON(4) * (C6 + FS6SP)
      TRM20 = TRM14
      TRM21 = TRM15
      TRM22 = 0.1428E-10 * CON(7) * (C6 + FS3SP)
      TRM23 = 0.285E-10 * CON(7) * (C6 + FS4SP)
      TRM24 = 0.428E-10 * CON(7) * (C6 + FS5SP)
      TRM25 = 0.57E-10 * CON(7) * (C6 + FS6SP)
      J55 = 0
      INDXS = 1
      N = 14
22222 DERIV(1,1) = -2.0*CON(9) - TRM13 * T(14)
      ST2 = C1 * CON(1) * T(14)
      DERIV(2,1) =  2.092 * C1 * CON(1) * T(14)
      DERIV(3,1) =  1.046 * C3 * CON(1) * T(14)
      DERIV(14,1) = -CON(1) * (2.092*C1*( T(1)-T(2)) + 1.046*C3 *
     1 ( T(1) - T(3)) )
      DERIV(1,2) = 1.046 * ST2
      DERIV(2,2) = -DERIV(1,2) - T(14) * ( CON(2) * 1.272 +
     1TRM14 * T3(2) * 4.0   )
      DERIV(3,2) = 1.272 * CON(2) * T(14)
      DERIV(14,2) = 1.046*C1*CON(1)*( T(1)-T(2) ) -1.272 * CON(2) *
     1 ( T(2) - T(3) ) - TRM14 * ( T(2) * T3(2) - TS4 )
      DERIV(1,3) = 0.523 * C3 * CON(1) * T(14)
      DERIV(2,3) = DERIV(3,2)
      DERIV(3,3) =-T(14) * (0.523 * C3 * CON(1) + 1.272*CON(2) +
     1 10.0 * CON(3) + TRM15 * T3(3) * 4.0)
      DERIV(4,3) = 10.0 * CON(3) * T(14)
      DERIV(14,3) = CON(1) *  0.523 * C3 *(T(1) - T(3)) + 1.272 * CON(2)
     1 * (T(2) - T(3)) - 10.0 * CON(3) * (T(3) - T(4)) + TRM15 * (TS4 -
     2 T3(3) * T(3))
      DERIV(3,4) = 10.0 * CON(3) * T(14)
      DERIV(4,4) =-(13.33 * CON(3) + TRM16 * T3(4) * 4.0 ) * T(14)
      DERIV(5,4) = 3.33 * CON(3) * T(14)
      DERIV(14,4) = CON(3) * (10.0 * T(3) - 13.33 * T(4) + 3.33 * T(5))
     1 + TRM16 * (TS4 - T3(4) * T(4))
      DERIV(4,5) = DERIV(5,4)
      DERIV(5,5) = -T(14) * (5.33 * CON(3) + TRM17 * 4.0 * T3(5))
      DERIV(6,5) = 2.0 * CON(3) * T(14)
      DERIV(14,5) = CON(3) * (3.33 * T(4) - 5.33 * T(5) + 2.0 * T(6) )
     1 + TRM17 * (TS4 - T(5) * T3(5))
      DERIV(5,6) = DERIV(6,5)
      DERIV(6,6) = -T(14) * (3.428 * CON(3)        + TRM18 * 4.0 *T3(6))
      DERIV(7,6) = 1.428 * CON(3) * T(14)
      DERIV(14,6) = CON(3) * (2.0 *(T(5) - T(6)) + 1.428 *(T(7) - T(6)))
     1 + TRM18 * (TS4 - T3(6) * T(6))
      DERIV(6,7) = DERIV(7,6)
      DERIV(7,7) = -T(14) * (1.428 * CON(3) + TRM19 * 4.0 * T3(7) )
      DERIV(14,7) = 1.428 * CON(3) * (T(6) - T(7)) + TRM19 *
     1 (TS4 - T3(7) * T(7))
```

FIGURE D-4 (cont'd)

```
      DERIV(1,8) = 2.0 * CON(9) - CON(1) * T(14) *
     1 (0.6973 * C1 + 0.3487 * C3)
      DERIV(8,8) = 0.6973 * C1 * 3.0 * CON(1) * T(14)
      DERIV(9,8) = 0.3487 * C3 * 3.0 * CON(1) * T(14)
      DERIV(14,8) = -CON(1) * ( 0.6973*C1 * (2.0*TOUT+T(1)-3.0*T(8)) +
     1 0.3487*C3* (2.0*TOUT+T(1)-3.0*T(9)) )
      DERIV(1,9) =   0.3487 * C1 * T(14) * CON(1)
      DERIV(8,9) = - T(14) * (1.046  * C1 * CON(1) + CON(2) *  1.272
     1    + TRM20 * 4.0 * T3(8) )
      DERIV(9,9) = DERIV(3,2)
      DERIV(14,9) = CON(1) * (0.3487 * C1 * (2.0 * TOUT + T (1) - 3.0 *
     1 T(8))) +CON(2)*1.272 *(T(9)-T(8))-TRM20* (T3(8)*T(8)-TS4 )
      DERIV(1,10) =   0.1743 * C3 * CON(1) * T(14)
      DERIV(8,10) = DERIV(3,2)
      DERIV(9,10) = -T(14) * (0.5229 * C3 * CON(1) + 1.272 * CON(2)
     1 + 10.0 * CON(5) + 4.0   * TRM21 * T3(10) )
      DERIV(10,10) = 10.0 * CON(5) * T(14)
      DERIV(14,10) = CON(1) * 0.1743 * C3 * (2.0 * TOUT - 3.0 * T(9)
     1 + T(1) ) + 1.272 * CON(2) * (T(8) - T(9)) + 10.0 * CON(5) *(T(10)
     2 - T(9)) +                TRM21 * (TS4 - T3(9) * T(9) )
      DERIV(9,11) = DERIV(10,10)
      DERIV(10,11) =-T(14) * (13.33 * CON(5) + 4.0 * T3(10) * TRM22)
      DERIV(11,11) = 3.33 * CON(5) * T(14)
      DERIV(14,11) =  10.0 * CON(5) * (T(9) -T(10) ) + 3.33 * CON(5)
     1 * (T(11) - T(10) ) + TRM22 * (TS4 - T(10) * T3(10) )
      DERIV(10,12) = DERIV(11,11)
      DERIV(11,12) = -T(14) * (5.33  * CON(5) + 4.0 * TRM23 * T3(11) )
      DERIV(12,12) = 2.0    * CON(5) * T(14)
      DERIV(14,12) = CON(5) * (3.33* T(10) - 5.33  * T(11) + 2.0    *
     1 T(12)) + TRM23  * (TS4 - T3(11) * T(11) )
      DERIV(11,13) = DERIV(12,12)
      DERIV(12,13) = -T(14) * (3.428 * CON(5) + 4.0 * TRM24 * T3(13))
      DERIV(13,13) = 1.428 * CON(5) * T(14)
      DERIV(14,13) = 2.0 * CON(5) * (T(11) - T(12)) +1.428 * CON(5) *
     1 (T(13) - T(12)) + TRM24 * (TS4 - T3(12) * T(12))
      DERIV(12,14) = DERIV(13,13)
      DERIV(13,14) = -T(14) * (1.428 * CON(5) + 4.0 * TRM25 * T3(13))
      DERIV(14,14) = 1.428 * CON(5) * (T(12) - T(13)) + TRM25 * (TS4 -
     1 T3(13) * T(13) )
      ERROR(1) = CON(9) * (3.0*TC-TOUT-2.0 * T(1)) - CON(1) * T(14) *
     1 ( 2.092*C1*( T(1)-T(2) ) + 1.046 * C3 * (T(1) - T(3) ) )
      ERROR(2) = T(14) * (1.046 * C1 * CON(1) * (T(1) - T(2)) + 1.272 *
     1 CON(2) * (T(3) - T(2)) + TRM14 * (TS4 - T(2) * T3(2)) )
      ERROR(3) = T(14) * (0.523 * C3 * CON(1) * (T(1) - T(3)) + 1.272 *
     1 CON(2) * (T(2) - T(3)) + 10.0 * CON(3) * (T(4) - T(3)) + TRM15 *
     2 (TS4 - T3(3) * T(3)) )
      ERROR(4) = T(14) * (10.0 * CON(3) * (T(3) - T(4)) + 3.33 * CON(3)
     1 * (T(5) - T(4)) + TRM16 * (TS4 - T3(4) * T(4)) )
      ERROR(5) = T(14) * (3.33 * CON(3) * (T(4) - T(5)) + 2.0 * CON(3) *
     1 (T(6) - T(5))+ TRM17 * (TS4 - T3(5) * T(5)) )
      ERROR(6) = T(14) * (2.0 * CON(3) * (T(5) - T(6)) + 1.428 * CON(3)
     1 * (T(7) - T(6)) + TRM18 * (TS4 - T3(6) * T(6)) )
      ERROR(7) = T(14) * (1.428 * CON(3) * (T(6) - T(7)) + TRM19 * (TS4
     1 - T3(7) * T(7)) )
      ERROR(8) = 2.0 * CON(9) * (T(1) - TOUT)  - T(14) * CON(1) *
     1 (0.6973*C1*(2.0*TOUT+T(1)-3.0*T(8)) + 0.3487*C3*(2.0*TOUT+T(1)
     2 - 3.0*T(9)) )
      ERROR(9) = T(14) * (CON(1) *  0.3487  * C1 * (2.0 * TOUT + T(1) -
```

FIGURE D-4 (cont'd)

```
     1 3.0 * T(8)) + CON(2) * 1.272 * (T(9) - T(8)) + TRM20 * (TS4 -
     2 T3(8) * T(8)) )
      ERROR(10) = T(14) * (CON(1) * 0.1743 * C3 * (2.0 * TOUT - 3.0 *
     1 T(9) + T(1)) + CON(2) * 1.272       * (T(8) - T(9)) + 10.0 *CON(5)
     2 * (T(10) - T(9)) + TRM21 * (TS4 - T(9) * T3(9)) )
      ERROR(11) = T(14) * (10.0 * CON(5) * (T(9) - T(10)) + 3.33 *CON(5)
     1 * (T(11) - T(10)) + TRM22 * (TS4 - T3(10) * T(10)) )
      ERROR(12) = T(14) * (3.33* CON(5) * (T(10) - T(11))+ 2.0  * CON(5)
     1 * (T(12) - T(11)) + TRM23 * (TS4 - T3(11) * T(11)) )
      ERROR(13) = T(14) * (2.0 * CON(5) * (T(11) - T(12)) +1.428 *CON(5)
     1 * (T(13) - T(12)) + TRM24 * (TS4 - T3(12) * T(12)) )
      ERROR(14) = T(14) * (1.428 * CON(5) * (T(12) - T(13)) + TRM25 *
     1 (TS4 - T3(13) * T(13)) )
      A1=  TF * EKF  * W45 / T(14)   * .001389
      DO 7012   I =  4,7
      A2  = I - 3
      A2A1 =  A2 * A1
      DERIV(I,I) = DERIV(I,I)- A2A1
      DERIV(I+6,I) = DERIV(I+6,I) +  A2A1
      DERIV(I+6,I+7) = DERIV(I+6,I+7) - A2A1
      DERIV(I,I+7)   = DERIV(I,I+7)  +  A2A1
      A3 =  A2A1 / T(14) * (T(I) - T(I+6))
      DERIV(14,I) = DERIV(14,I) + A3
      DERIV(14,I+7)= DERIV(14,I+7) - A3
      ERROR(I) = ERROR(I) - A3 * T(14)
 7012 ERROR(I+7) = ERROR(I+7) + A3 * T(14)
      A1 = (DOIN * DOIN - DIIN * DIIN) * EKTH  / T(14)
      A2 =  .00363 * C1 * A1
      A3 =  .00182 * C3 * A1
      DERIV(2,2) = DERIV(2,2) - A2
      DERIV(8,2) = DERIV(8,2) + A2
      A4 = (T(2)- T(8)) * A2
      DERIV(14,2) = DERIV(14,2) + A4 / T(14)
      ERROR(2) = ERROR(2) - A4
      DERIV(2,9) = DERIV(2,9) + A2
      DERIV(8,9) = DERIV(8,9) - A2
      DERIV(14,9)= DERIV(14,9) - A4  / T(14)
      ERROR(9)    = ERROR(9) + A4
      DERIV(3,3) =  DERIV(3,3) - A3
      DERIV(9,3) =  DERIV(9,3) + A3
      A4  =  (T(3) - T(9)) * A3
      DERIV(14,3) = DERIV(14,3) + A4/T(14)
      ERROR(3)   = ERROR(3) - A4
      DERIV(3,10) = DERIV(3,10) + A3
      DERIV(9,10) = DERIV(9,10) - A3
      DERIV(14,10)= DERIV(14,10) -  A4 / T(14)
      ERROR(10)    = ERROR(10)  +  A4
      DO 702 I = 1,N
  702 DERIV(N+1,I) =-ERROR(I)
      CALL CROUT
      GO TO (28,7005) ,INDXS
 7005 GO TO (7006,7007,9753),INSR
 7006 INSR=2
      T(14)=1.
      GO TO 7003
 7007 INSR=3
      T(14)=5.
      GO TO 7003
```

FIGURE D-4 (cont'd)

```
 9753   WRITE (ITP2,9754) DIIN ,EN ,  WINA
 9754   FORMAT(5H DIIN,F10.5,5X1HNF14.5,5X4HWINAF11.5,5X
       1 50HSUBCOOLER EQUATIONS NONCONVERGENT AFTER 20 TRIES    )
        GO TO 89
 204    GO TO 22222
 28     DO 207 I = 1,14
        T(I) = T(I) + DELTA(I)
        T3(I) = T(I) * T(I) * T(I)
        DO 207 J =1,14
 207    DERIV(J,I) = 0.0
        IF(ABS (DELTA(14))-.01) 802,204,204
 802    DO 803 I = 1,13
        IF(ABS(DELTA(I))-1.)803,204,204
 803    CONTINUE
 206    ELSCX = T(14)
        ELTX = ELC + ELSCX
        ENPG = 144. / (RHOL *ELSCX)* (ST7/9260.-DPLC)
        IF(ELTMX)36,36,35
 35     IF(ELTX -ELTMN)352,351,351
 351    IF(ELTMX-ELTX) 352,36 ,36
 352    WRITE (ITP2,2003)  DIIN,EN,WINA,ELTX
 2003   FORMAT(5H DIIN,F10.5,5X1HNF14.5,5X4HWINAF11.5,5X3HLTXF13.5,
       1  5X12HOUT OF RANGE )
        GO TO 89
 36     IF(TTG) 2063,2063,2064
 2063   TTX = TT * (ELTX * DOIN / (ELT * DIIN)) **0.25 - Z7 * C9 * TF /
       1 (RHOT * EMETH * EMETH / (RHOF * EMEF * EMEF)) ** 0.1666
 2064   DOINX = 2.0 * TTX + DIIN
        WBRIX = 0.0833 * Z5 * EN * (2.0 * WINA + DOINX) + 3.14 * Z6* DCMIN
        WBREX = Z5 * WBRIX + 3.14 * Z6 * DCMAJ
        ST72 = DIIN * DIIN
        EMT = 0.00545 * RHOT * (DOINX * DOINX - ST72) * (EN * ELTX+ WBREX)
        ST73 = ELTX + (WBRIX + WBREX)
        ST79 = Z5 * WINA
        WINXX = ST79 + ST80 * (37.7 * DCMIN /EN - DOINX)
        WOUXX = ST79 + ST80 * (37.7 * DCMAJ /EN - DOINX)
        EMF = 0.01388 * (3.0 * RHOF * TF * C8 * ST73 + ELTX * EN *
       1 0.5*(WINXX+WOUXX) * (1.0 - C8))
        EMIF = 0.0417 * RHOIF * TIF * ST73
        DIINH = 1.414 * DIHA
        ST75 = DIHA + 2.0*TH
        EMIH = 0.00545 * RHOH * WBRIX * (ST75 * ST75 - DIHA * DIHA)
        EMLI = 0.00545 * ST72 * RHOL * (EN * ELSCX + WBREX)
        EMCR = EMT + EMF + EMIF + EMIH + EMLI
        ACR = ST73 / 2.0
        QTOTS = ST81 * CL * (TC - TOUT)
        ENUE = -ENUE
        ENPG = -ENPG
        WRITE (ITP2 ,3579)
 3579   FORMAT(//)
        WRITE             ( ITP2,3003)DIIN,EN,WINA,VIN,DIINH,DIHA,WBRIX,
       1DPIH,WBREX,TTX,DOINX,ELC,ELSCX,ELTX,DPLC,WINXX,WOUXX,TF,
       2QTOTC,QFTC,QTTC,QTOTS,FEFC,ENUE,ENPG,EMT,EMF,EMIF,EMIH,EMLI,
       3EMCR,ACR
 3003   FORMAT(11X4HDIIN14X1HN11X4HWINA12X3HVIN,10X5HDIINH11X4HDIHA10X5HWB
       1R1X11X4HDPIH/11X4HINCH26X4HINCH9X6HFT/SEC11X4HINCH11X4HINCH13X2HFT
       212X3HPSI/8F15.5/10X5HWBREX12X3HTTX10X5HDOINX13X2HLC11X4HLSCX12X3HL
       3TX11X4HDPLC10X5HWINXX/13X2HFT11X4HINCH11X4HINCH13X2HFT13X2HFT13X2H
```

FIGURE D-4 (cont'd)

```
     4FT12X3HPSI11X4HINCH/8F15.5/10X5HWOUXX13X2HTF10X5HQTOTC11X4HQFTC
     511X4HQTTC10X5HQTOTS11X4HFEFC12X3HNUE/
     611X4HINCH11X4HINCH11X4HB/HR11X4HB/HR11X4HB/HR11X4HB/HR21X9HNO OF G
     7,S/1F15.5,1F15.8,4F15.1,2F15.5/12X3HNPG13X2HMT13X2HMF12X3HMIF12X3H
     8MIH12X3HMLI12X3HMCR12X3HACR          /6X9HNO OF G,S12X3HLBS12X3HLBS
     912X3HLBS12X3HLBS12X3HLBS12X3HLBS10X5HSQ FT/8F15.5//)
  89  IF(WNMAX - WINA) 91, 91, 90
  90  WINA = WINA + WNDEL
      GO TO 38
  91  IF(ENMAX - EN) 93, 93, 92
  92  EN = EN + ENDEL
      GO TO 3
  93  IF(DMAX - DIIN) 95, 95, 94
  94  DIIN = DIIN + DDEL
      GO TO 2
  95  CONTINUE
      GO TO 1
      END

      SUBROUTINE TABLE
      DIMENSION CCC(9,3)  ,ZZZ(9,5) ,C(9)  , Z(9),DERIV(15,14),DELTA(14)
      COMMON  N, J55,  IHALT, INDXS, ITP1,ITP2,
     1 DERIV, DELTA, C, Z, Y1, Y2, Y3, Y4
C     CREATE RADIATOR INPUT TABLE
C     PROGRAM CONSTANTS - SELECTION
      DATA CCC,ZZZ/3*1.,0,3*0,0,1.,2*0.0,1.125,.5,.75,0.,2*1.,.82,1.,.25,
     1,.75,1.,1.5,0.,2.,2*0.,1.,.5,5*1.,0.,1.,0.,1.,1.,.5,0.,2*1.,0.,4.,2
     2*1.,1.5,3*.866,1.,0.,1.,0.,3.,2.,3*.707,1.,0.,1.,0.,4.,1.,.5,0.,1.
     3,0.,1.,4.,1.,1./
      READ (ITP1,1002) I,J,K,L
1002  FORMAT(4I1)
      WRITE            ( ITP2,1005)I,J,K,L
1005  FORMAT(/8H PUNT IS 2X4I1/)
      CCC(4,1)  = 0.5
      DO  1   I1  = 1,9
      C(I1)   =   CCC(I1,I)
   1  Z(I1)   =   ZZZ(I1,J)
      GO TO (16,15,16,16,15),J
  15  Z(3)  = C(4)
  16  CONTINUE

      IF(K-1) 2  ,  2  ,  3
   2  Y1  = 1.
      Y2  = 0.
      GO TO 4
   3  Y1  =   0.
      Y2  =   1.
   4  IF(L - 1)   5  ,  5  ,  6
   5  Y3  = 1.
      Y4  = 0.
      RETURN
   6  Y3  = 0.
      Y4  = 1.
      RETURN
      END
```

FIGURE D-4 (cont'd)

```
      SUBROUTINE CROUT
      DIMENSION A(15,14), H(14)
      COMMON  N, J55,  IHALT, INDXS, ITP1,ITP2,A,H
      N1=N+1
      DO 200 K=1,N
      K1=K+1
      J=K
      DO 100 I=K,N
      SUM=0.0
      IF(J-1)10,13,10
   10 IF(I-1)13,13,11
   11 IF(I-J)17,17,21
   17 ISMX=I-1
      DO 12 IS=1,ISMX
   12 SUM=SUM+A(IS,I)*A(I,IS)
   13 A(J,I)=A(J,I)-SUM
      GO TO 100
   21 JSMX=J-1
      DO 22 JS=1,JSMX
   22 SUM=SUM+A(JS,I)*A(J,JS)
   23 A(J,I)=A(J,I)-SUM
  100 CONTINUE
      I=K
      DO 200 J=K1,N1
      SUM=0.0
      IF(I-1)233,233,231
  231 ISMX=I-1
      DO 232 IS=1,ISMX
  232 SUM=SUM+A(IS,I)*A(J,IS)
  233 IF(A(I,I))350,351,350
  351 A(J,I)=0.0
      GO TO 200
  350 A(J,I)=(A(J,I)-SUM)*(1./A(I,I))
  200 CONTINUE
C     HAVE COMPLETED FINDING THE DERIVED MATRIX
      DO 300 IS=1,N
      SUM=0.0
      JS=N-IS+1
      JS1=JS+1
      DO 280 KS=JS1,N
      IF(KS-N)280,280,300
  280 SUM=SUM+A(KS,JS)*H(KS)
  300 H(JS)=A(N1,JS)-SUM
      J55=J55+1
      IF(20-J55) 302,302,303
  302 IHALT = 99
      INDXS = 2
  303 RETURN
      END
```

FIGURE D-4 (cont'd)

COMPUTER FLOW CHART - PRIMARY/SECONDARY DESIGN PROGRAM

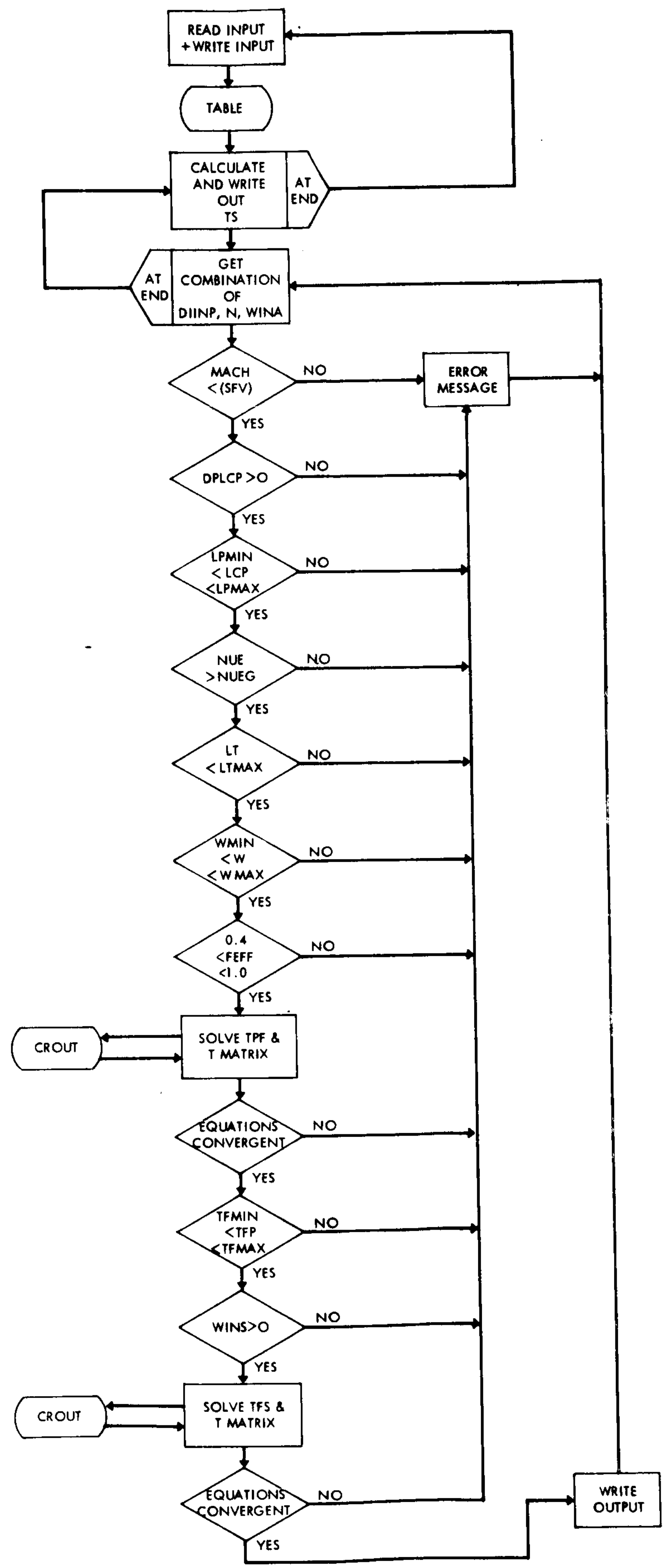

Figure D-5

SOURCE DECK PRINTOUT
PRIMARY/SECONDARY DESIGN PROGRAM

```
      DIMENSION  REV(3),FR(3),WFF(3),RE(3),DR(3),PHI(3),STOR(18),TS(12),
     1 QIS(12),QIT(12),TS4(12),DERIV(8,7),DELTA(7),T(7), T3(7)
     2 , TITLE(16)
      COMMON N,J55,IHALT,INDXS,DERIV,DELTA,C1,C2,C3,C4,C5,C6,C7,C8,C9,
     1 Z1,Z2,Z3,Z4,Z5,Z6,Z7,Z8,Z9,Y1,Y2,Y3,Y4,ITP1,ITP2
      DATA STOR / 6*0.0 ,    .00431,.00531,.00764,.138,.17,.244,4.33,
     1 5.33,7.68,1.126,1.54,2.650/
      ITP1 = 5
      ITP2 = 6
      N = 7
1     READ (ITP1,1003) TITLE
1003  FORMAT(16A5)
      WRITE (ITP2,1003) TITLE
      READ (ITP1, 1000)          INTS, (TS(I),QIS(I),QIT(I),I=1,INTS)
1000  FORMAT(I2/,(3F10.4))
      READ ( ITP1,1001)         PC,TC,EMDT,XIN,DPTOT,TOUT,R,GAMMA,VISV,
     1VISL,HFG,CL,RHOL,SUFT,EKC,RHOT,RHOF,EKTH,EKF,RHOH,TH,FSV,FT,EF,
     2CV,TIN,TAU,ELNPO,EMFF,EMETH,TTG,ENUEG,TFMIN,TFMAX,ELPMN,ELPMX,
     3WMIN,WMAX,TIF,RHIF,ELTMX,ALPHS,ALPHT
     4                              , DINPL,DINPH,DINPD,ENL,ENH,ENDEL,WINAL,
     5WINAH,WINAD
1001  FORMAT(8F10.4)
      CALL TABLE
      WRITE (ITP2,6037) PC,TC,EMDT,XIN,DPTOT,TOUT,R,GAMMA,VISV,VISL,HFG,
     1 CL,RHOL,SUFT,EKC,RHOT,RHOF,EKTH,EKF,RHOH,TH,FSV,FT,EF
```

FIGURE D-6

```
6037  FORMAT(50H DESIGN PROGRAM ISO-PRIM/SEC DIRECT R/C W/SC        /     1
     12H FIXED INPUT/13X2HPC13X2HTC12X3HMDT12X3HXIN10X5HDPTOT11X4HTOUT1
     2X1HR10X5HGAMMA/11X4HPSIA10X5HDEG R8X7HLBS/MIN27X3HPSI10X5HDEG R11X
     34HFT/R/8F15.5//11X4HVISV11X4HVISL12X3HHFG13X2HCL11X4HRHOL11X4HSUFT
     413X2HKC11X4HRHOT/2(5X10HLBS/FT SEC)11X4HB/LB9X6HB/LB F6X9HLBS/CU,F
     5T9X6HLBS/FT6X9HB/HR FT F6X9HLBS/CU,FT/2F15.9,6F15.5
     6 //11X4HRHOF12X3HKTH13X
     72HKF11X4HRHOH13X2HTH12X3HFSV13X2HFT13X2HEF/6X9HLBS/CU.FT6X9HB/HR F
     8T F6X9HB/HR FT F6X9HLBS/CU,FT11X4HINCH/8F15.5/)
      WRITE (ITP2,6038)CV,TIN, TAU, ELNPO,EMEF,EMETH,TTG,ENUEG,TEMIN,
     1 TEMAX ,ELPMN,ELPMX,WMIN,WMAX,TIF,RHIF,ELTMX,ALPHS, ALPHT ,
     2 DINPL,DINPH,DINPD,ENL ,ENH , ENDEL,WINAL,WINAH , WINAD
6038  FORMAT(13X2HCV12X3HTIN12X3HTAU10X5H-LNPO12X3HMEF11X4HMETH12X3HTTG
     111X4HNUEG/8X7HB/LBS F10X5HDEG R11X4HDAYS15X2(12X3HPSI)11X4HINCH6X
     29HNO OF 6,S/4F15.6,2F15.2,2F15.6//10X5HTEMIN10X5HTEMAX10X5HLPMIN10
     3X5HLPMAX11X4HWMIN11X4HWMAX12X3HTIF11X4HRHIF/2(11X4HINCH)4(13X2HFT)
     411X4HINCH6X9HLBS/CU.FT/8F15.5//10X5HLTMAX10X5HALPHS10X5HALPHT8X7HD
     5IINP 08X7HDIINP F8X7HDIINP D12X3HN 012X3HN F/13X2HFT30X3(11X4HINCH
     6)/8F15.5//12X3HN D9X6HWINA 09X6HWINA F9X6HWINA D/15X3(11X4HINCH)/
     7    4F15.5//)
      WINAH=WINAH-.000001
      ENH=ENH-.000001
      DINPH=DINPH-.000001
      ISL1=0
      IF(ELPMN) 515,510,513
510   IF(WMIN)  515,511,513
511   IF(TEMAX) 515,512,513
512   FFFF= .4
      GO TO 514
513   FFFF = 0.0
514   ISL1=1
515   CONTINUE
      PPWR=EMDT*DPTOT/ (236.0*RHOL)
      WRITE (ITP2,1002) PPWR
1002  FORMAT(8H PPWR IS           ,F13.8/)
      QSC = 60. * EMDT * CL * (TC - TOUT)
      QTOTP = EMDT * (52.5 * XIN * HFG + 60. * CV * (TIN - TC))
      QTOTS =  7.5   * EMDT * XIN * HFG
      RHOV = 144. * PC / (R * TC)
      SOVV = 5.67 * SQRT (R * TC * GAMMA)
      DISC = .782 * SQRT (EMDT /RHOL)
      DO 400 NUMBR = 1,INTS
      IF(TS(NUMBR)) 55, 56, 56
55    TS4(NUMBR) = 5.83E+08 * (QIS(NUMBR) * ALPHS / ALPHT + QIT(NUMBR))
      GO TO 57
56    TS4(NUMBR) = TS(NUMBR)*TS(NUMBR)*TS(NUMBR)*TS(NUMBR)
57    WHOTS=TS4(NUMBR)**.25
      WRITE (ITP2,8764) WHOTS
8764  FORMAT(/7H TS IS F8.1,6H DEG R   ///)
2     DIINP = DINPL
3     EN = ENL
4     WINA = WINAL
      VIN = 3.06 * EMDT * XIN / (RHOV * DIINP * DIINP * EN)
      IF(VIN - FSV * SOVV) 11, 8,8
8     WRITE (ITP2,2000)              DIINP,EN,WINA,VIN
2000  FORMAT(5HDIINP,F10.5,5X,1HN,F14.5,5X,4HWINA,F11.5,5X,
     1 3HVIN,F12.5,5X,11HGT FSV,SOVV )
      GO TO 91
```

FIGURE D-6 (cont'd)

```
 11     DIHA = .5 * DIINP * SQRT (EN / Z1)
        REIHA = RHOV * DIHA * VIN / (12. * VISV)
        DEHA  = .25  * DIINP * SQRT (EN / Z1)
        REEHA = RHOV * DEHA * VIN / (24. * VISV)
        REVIN = RHOV * DIINP * VIN / (12. * VISV)
        DIINS = .5   * DIINP * SQRT (EN)
 12     WBARI = .0833 * EN * (2.0 * WINA + .75 * DIINP)
        DPIH = .000103 * RHOV * VIN * VIN * WBARI / (Z1*DIHA*REIHA**.25)
        DPEH =.0001225 *RHOV * VIN * VIN * WBARI / (Z1*DEHA*REEHA**.25)
        DPLCP = .667 * (DPTOT - DPIH - DPEH + RHOV*VIN*VIN /74200. )
        IF(DPLCP) 13, 13, 14
 13     WRITE (ITP2,2001)          DIINP,EN,WINA,DPLCP
 2001   FORMAT(5HDIINP,F10.5,5X,1HN,F14.5,5X,4HWINA,F11.5,5X,
      1 5HDPLCP,F10.5,5X,8HNEGATIVE  )
        GO TO 89
 14     STOR (1) = .924
        STOR (2) = .75
        STOR (3) = .521
        STOR (4) = .854
        STOR (5) = .563
        STOR (6) = .272
        DO 28 I = 1,3
        REV(I) = STOR(I) * REVIN
        IF(REV(I) - 2000.)17, 17, 18
 17     FR(I) = 64. / REV(I)
        GO TO 19
 18     IF(REV(I) - 4000.0) 15,16,16
 15     FR(I) = 0.00277 * REV(I) ** 0.322
        GO TO 19
 16     FR(I) = .316 / REV(I) ** .25
 19     WEF(I) = STOR(I+6) * EMDT * VIN * SQRT (RHOV / RHOL) * (1.0 -
      1 STOR(I+3) * XIN) / (SUFT * DIINP * EN)
        RE(I) = STOR(I+9) * EMDT * (1.0 - STOR(I+3)*XIN)/(DIINP*EN*VISL)
        IF(WEF(I) - 3.0) 20, 20, 22
 20     IF(RE(I) - 200.0) 21, 21, 22
 21     DR(I) = STOR(I+12) * SQRT ((1.0 - STOR(I+3)*XIN)*VISL*RHOV /
      1 (FR(I) * REV(I) * XIN * VISV * RHOL))
        IF(REV(I) -2000.0) 23,23,24
 23     PHI(I) = (1.0 + DR(I)) ** 4.0
        GO TO 28
 24     PHI(I) = ( 0.5 + SQRT ( 0.25 + DR(I)) ) ** 4.75
        GO TO 28
 22     PHI(I) = STOR(I+15) / XIN ** .75
 28     CONTINUE
        HCOND = Y1 * Y4 * 1.375* VIN * SQRT (CL * RHOL * RHOV * EKC *
      1 FR(2) / VISL) + 2000.0 * Y3 * Y1 + 5000.0 * Y2
        FLCP = 2320. * DPLCP * DIINP / (RHOV * VIN * VIN * (PHI(1) * FR(1)
      1 * 1.082 + 1.333 * PHI(2)* FR(2) + 1.92 * PHI(3) * FR(3)))
        IF(FLPMX) 32,32, 29
 29     IF(FLCP - FLPMN) 31,31, 30
 30     IF(FLPMX - FLCP) 31, 31,32
 31     WRITE (ITP2,2002)          DIINP,EN,WINA,FLCP
 2002   FORMAT(5HDIINP,F10.5,5X,1HN,F14.5,5X,4HWINA,F11.5,5X,
      1 3HLCP,F12.5,5X,12HOUT OF RANGE  )
        GO TO 89
 32     ENUF = 12.9E-04 * (DIINP * EN / (VISL * EMDT * RHOL))** .33333
      1 * (RHOV*VIN*VIN / REVIN**.25 + 6.18*EMDT*VIN/(DIINP*FLCP*EN))
        IF(ENUEG) 35,35,33
```

FIGURE D-6 (cont'd)

```
33    IF(FNUEG - FNUE) 35, 35 ,34
34    WRITE (ITP2,2003)            DIINP,EN,WINA,FNUE
2003  FORMAT(5HDIINP,F10.5,5X,1HN,F14.5,5X,4HWINA,F11.5,5X,
     1 3HNUE,F12.5,5X,12HOUT OF RANGE   )
      GO TO 89
35    DPLCS = .5 * DPLCP
      ELCS=574.0*DPLCS*REVIN**0.25 *DIINS*EN**0.125/(RHOV*VIN*VIN)
      ELSCS = ELCS* CL * TC * (TC*TC*TC/(TOUT*TOUT*TOUT)-1.)/(.375 *HFG)
      FLTS = ELCS + ELSCS
      ELT = ELCP + FLTS
      IF(FLTMX) 38,38,36
36    IF(FLTMX - FLT) 37, 37, 38
37    WRITE (ITP2,2004)            DIINP,EN,WINA,FLT
2004  FORMAT(5HDIINP,F10.5,5X,1HN,F14.5,5X,4HWINA,F11.5,5X,
     1 2HLT,F13.5,5X,12HOUT OF RANGE   )
      GO TO 89
38    ATP = .1965 * EN * DIINP * ELCP * Z2
      ATS = .1965 * DIINS * ELCS
      AP = ATP + ATS
      IF(TTG) 40,40,39
39    TT = TTG
      TTP = TTG
      GO TO 41
40    TT = 3.31 * (AP*TAU /ELNPO)**.25 / (RHOT*FMETH*FMETH)**.16666
41    DOAVP = .75 * DIINP + 2.0 * TT
      INDEX = 1
      IF(WMAX) 45,45,42
42    STORE = .0833 * EN * (2.0 * WINA + DOAVP)
      IF(STORE - WMIN)  44,44,43
43    IF(WMAX - STORE)  44,44,45
44    WRITE (ITP2,2005)            DIINP,EN,WINA,STORE
2005  FORMAT(5HDIINP,F10.5,5X,1HN,F14.5,5X,4HWINA,F11.5,5X,
     1 1HW,F14.5,5X,12HOUT OF RANGE   )
      GO TO 89
45    STORE = DOAVP / WINA
      QTUB=0.2857E-09 * Z2*FF*DOAVP*ELCP*EN*(TC*TC*TC*TC-TS4(NUMBR))
6000  J55 = 0
      IF (C5) 47, 46, 47
46    F3SP = SQRT (.05 * STORE + .0025) / (STORE + .1)  +
     1  SQRT (1.95 * STORE + 3.803) / (STORE + 3.9)
      F4SP = SQRT (0.2 * STORE + .04 ) /  (STORE + .4)  +
     1  SQRT (1.8 * STORE + 3.24 )  / (STORE + 3.6)
      F5SP = SQRT (.45 * STORE +.2025)  / (STORE + .9)  +
     1  SQRT (1.55 *STORE + 2.403)  / (STORE + 3.1)
      F6SP = SQRT (0.8 * STORE + .64 )  / (STORE + 1.6) +
     1  SQRT (1.2  * STORE + 1.44)  / (STORE + 2.4)
      F1SP = 0.6366 * (1.+(2.0/STORE) * (1.0-SQRT (0.5*STORE+1.0)) +.5*
     1 ATAN (SQRT   (8.0/STORE * (1.0 + 2.0 / STORE)) ) )
47    IF(C5-1.0) 50,48,50
48    IF(Z3) 49,52,49
49    F3SP = (.05 * STORE + .0025) / (STORE * (STORE + .1) + .005) +
     1 (1.95 * STORE + 3.803) / (STORE * (STORE + 3.9) + 7.606)
      F4SP = (.2 * STORE + .04) / (STORE * (STORE + .4) + .08) +
     1 (1.8 * STORE + 3.24) / (STORE * (STORE + 3.6) + 6.48)
      F5SP = (.45 * STORE + .2025) / (STORE * (STORE + .9) + .405) +
     1 (1.55 * STORE + 2.403) / (STORE * (STORE + 3.1) + 4.806)
      F6SP = (.8 * STORE + .64) / (STORE * (STORE + 1.6) + 1.28)  +
     1 (1.2 * STORE + 1.44) / (STORE * (STORE + 2.4) + 2.88)
```

FIGURE D-6 (cont'd)

```
      F1SP = 0.3183 * (ATAN (1.0 + 4.0 / STORE) + 0.2146)
50    IF(C5-2.0) 53,52,53
52    F3SP = 1.0
      F4SP = 1.0
      F5SP = 1.0
      F6SP = 1.0
      F1SP = 1.0
53    GO TO ( 54, 68),INDEX
54    IF(ISL1) 61,61,58
58    STORE=(-GTUB+(2.1E+11*EMDT*(0.875*XIN*HFG+CV*TIN-CV*TC))) /
     1 ( EN     * 2.0 * WINA   * FLCP *(TC*TC*TC*TC-TS4(NUMBR))*EF*72)
      IF(STORE - FEFF) 60, 59, 59
59    IF(1.0 - STORE) 60, 61, 61
60    WRITE (ITP2,2006)              DIINP,EN,WINA,STORE
2006  FORMAT(6H DIINP,F9.5,5X,1HN,F14.5,5X,4HWINA,F11.5,5X,
     1 4HFEFF,F11.5,5X,12HOUT OF RANGE   )
      GO TO 89
61    DIAVP = .75 * DIINP
      DIIN = DIAVP
      DOIN = DCAVP
      XLC = FLCP
      XWIN = WINA
      STOR(1) = Z3
      STOR(2) = Z4
      STOR(3) = Z2
      STOR(4)=-EMDT/EN*(17.5*XIN*HFG+20.0*CV*(TIN-TC))
      STORE =(TC- TOUT) / 6.0
      INDEX = 1
6999  INSR=1
7000  T(1)=TC-10.
      T(2)=T(1)-5.
      J55=0
      DO 6555 I=3,6
6555  T(I)=T(I-1)-30.
      DO 62 I = 1,6
62    T3(I) = T(I) * T(I) * T(I)
      GO TO (6101,6102),INSR
6101  T(7)=.01
      INSR=2
      GO TO 6740
6102  T(7)=.1
      INSR=3
6740  DO 621 I=1,7
      DO 621 J=1,8
621   DERIV(J,I)=0.0
      STOR(5) = DIIN / (24./HCOND + (DOIN - DIIN)/EKTH)
      STOR(6) = C2 * EKTH * (DOIN - DIIN) / (DOIN + DIIN)
      DERIV(1,1) =-1.394 * C1 * STOR(5) * XLC - 1.7 * STOR(6) * XLC -
     14.*1.495E-10*F1SP* STOR(1) * C7 * DOIN * XLC * FT * T3(1)
      DERIV(2,1) = 1.7 * STOR(6) * XLC
      DERIV(8,1) = 1.394 * C1 * STOR(5) * XLC * (T(1)-TC) - 1.7 *STOR(6)
     1 *XLC*(T(2)-T(1))-1.495E-10*F1SP*STOR(1)*C7*DOIN*XLC*FT*
     2 (TS4(NUMBR) - T3(1) * T(1))
      DERIV(1,2) = DERIV(2,1) / 2.0
      DERIV(3,2) = 6.67 * T(7) * XLC / XWIN * EKF
      DERIV(2,2) = -.348 * C3 * STOR(5) *XLC-DERIV(3,2) - DERIV(1,2) -
     1 4.0 * .238E-10 * STOR(2) * C5 * EF * DOIN * XLC * T3(2)
      DERIV(8,2) = .348 * C3 * STOR(5) * XLC * (T(2) - TC) + DERIV(1,2)
```

FIGURE D-6 (cont'd)

```
      1 * (T(2) - T(1)) - DERIV(3,2) * (T(3) - T(2)) -.238E-10 * STOR(2)
      2 * C5 * EF * DOIN * XLC * (TS4(NUMBR) - T3(2)*T(2))
       DERIV(7,2) = 6.67 * XLC / XWIN * EKF * (T(3) - T(2))
       STORE = XLC / XWIN  * EKF
       DERIV(2,3) = 6.67 * STORE * T(7)
       DERIV(4,3) = 2.22 * STORE * T(7)
       DERIV(7,3) = STORE * (6.67 * (T(2)-T(3)) - 2.22 * (T(3)-T(4)))
       DERIV(3,3) = - DERIV(2,3) - DERIV(4,3) - 4.0 * .95E-11 * STOR(3)
      1 * C2 * EF * XLC * XWIN * (C6 + F3SP) * T3(3)
       DERIV(8,3) =-DERIV(7,3) * T(7) - .95E-11 * STOR(3) * C2 * EF *
      1 XLC * XWIN * (C6 + F3SP) * (TS4(NUMBR)- T3(3)*T(3))
       DERIV(3,4) = DERIV(4,3)
       DERIV(5,4) = 1.334 * T(7) * STORE
       DERIV(7,4) = STORE * (2.22 * (T(3)-T(4)) - 1.334 * (T(4)-T(5)))
       DERIV(4,4) =-DERIV(3,4) - DERIV(5,4) - 4.0 * 1.9E-11 * STOR(3) *
      1 C2 * EF * XLC * XWIN * (C6 + F4SP) * T3(4)
       DERIV(8,4) =-DERIV(7,4) * T(7) - 1.9E-11 * STOR(3) * C2 * EF *
      1 XLC * XWIN * (C6 + F4SP) * (TS4(NUMBR) - T3(4) * T(4))
       DERIV(4,5) = DERIV(5,4)
       DERIV(6,5) = .952 * T(7) * STORE
       DERIV(7,5) = STORE * (1.334 * (T(4)-T(5)) -.952 * (T(5)-T(6)))
       DERIV(5,5) = -DERIV(4,5) - DERIV(6,5) - 4.0 * 2.85E-11 * STOR(3)
      1 * C2 * EF * XLC * XWIN * (C6 + F5SP) * T3(5)
       DERIV(8,5) =   - DERIV(7,5) * T(7) - 2.85E-11 * STOR(3) * C2 * EF
      1 * XLC * XWIN * (C6 + F5SP) * (TS4(NUMBR) - T3(5) * T(5))
       DERIV(5,6) = DERIV(6,5)
       DERIV(6,6) = - DERIV(6,5) - 4.0 * 3.8E-11 * STOR(3) * C2 * EF *
      1 XLC * XWIN * (C6 + F6SP) * T3(6)
       DERIV(7,6) = .952 * STORE * (T(5) - T(6))
       DERIV(8,6)=-T(7)*DERIV(7,6)-3.8E-11 * STOR(3) * C2 * EF * XLC *
      1 XWIN * (C6 + F6SP) * (TS4(NUMBR) - T3(6) * T(6))
       DERIV(1,7) = .697 * STOR(5) * XLC * 2.0 * C1
       DERIV(2,7) = .697 * STOR(5) * XLC * C3
       DERIV(8,7)=STOR(4)+.697 * STOR(5) * XLC * (2.0 * C1 * (TC - T(1))
      1 + C3 * (TC - T(2)))
       INDXS = 1
       CALL CROUT
       GO TO (7005 , 10 ),INDXS
 10    GO TO (6103,6104),INDEX
 6103  GO TO (7000,7000,8010),INSR
 6104  GO TO (7000,7000,8011),INSR
 8010  WRITE (ITP2,2007)           DIINP,EN,WINA
 2007  FORMAT(6H DIINP,F9.5,5X,1HN,F14.5,5X,4HWINA,F11.5,5X,
      1 52HPRIMARY-COND. EQUATIONS NONCONVERGENT AFTER 20 TRIES     )
       GO TO 89
 8011  WRITE (ITP2,8013)           DIINP,EN,WINA
 8013  FORMAT(6H DIINP,F9.5,5X,1HN,F14.5,5X,4HWINA,F11.5,5X,
      1 52HSECOND.-COND. EQUATIONS NONCONVERGENT AFTER 20 TRIES     )
       GO TO 89
 7005  DO 7004 I = 1,7
       T(I) = T(I) + DELTA(I)
 7004  T3(I) = T(I) * T(I) * T(I)
       DO 7001 I = 1,6
       IF(ABS (DELTA(I)) - 1.0  ) 7001, 7001,7003
 7001  CONTINUE
 7002  IF(ABS (DELTA(7)) -.0001)7006,7003,7003
 7003  GO TO 6740
 7006  GO TO ( 63 ,  71 ),INDEX
```

FIGURE D-6 (cont'd)

```
63     TFP = T(7)
       T12=T(2)
       IF(TFMAX)67, 67 ,64
64     IF(TFMAX - TFP)  66, 65, 65
65     IF(TFP - TFMIN)  66, 67, 67
66     WRITE (ITP2,2008)           DIINP,EN,WINA,TFP
2008   FORMAT(6H DIINP,F9.5,5X1HN,F14.5,5X4HWINA,F11.5,5X
      1 3HTFP,F12.5,5X,12HOUT OF RANGE  )
       GO TO 89
67     QFS = 3.75 * HFG * EMDT * XIN - .0143E-8 * (.75 * DIINS + 2. * TT)
      1 * ET * ELCS * (TC*TC*TC*TC-TS4(NUMBR))
       QTTP = DOIN * ELCP * (4.485 * F1SP * Z3 * C7 * ET *(T3(1)*T(1) -
      1 TS4) + 1.428*Z4 *C5 *EF *(T3(2)*T(2) - TS4)) * 1.E-10 * EN
       QFTP=QTOTP-QTTP
       TR4=(TC-(TC-T12)*(ELCP*DIINP*EN/(ELCS*DIINS*7.0)))**4.0
       WINS = 60.4E+8 * QFS / (ELCS * EF * (TR4-TS4(NUMBR)))
       IF(WINS) 69,70,70
69     WRITE (ITP2,2009)           DIINP,EN,WINA,WINS
2009   FORMAT(6H DIINP,F9.5,5X1HN,F14.5,5X4HWINA,F11.5,5X
      1 4HWINS,F11.5,5X,12HOUT OF RANGE  )
       GO TO 89
70     DOAVS = .75 * DIINS + 2.0 * TT
       STORE = DOAVS / WINS
       INDEX = 2
       GO TO 6000
68     DIAVS = .75 * DIINS
       DIIN = DIAVS
       DOIN = DOAVS
       XLC = ELCS
       XWIN = WINS
       STOR(1) = 1.0
       STOR(2) = 1.0
       STOR(3) = 1.0
       STOR(4) = -2.5 * EMDT * XIN * HFG
       INSR=1
       GO TO 6740
71     IF(TTG)7101,7101,7102
7101   TTP=2.37*(Z2*TAU*(ELCP*DOAVP*EN+ELCS*DOAVS)/ELNPO)**0.25 /
      1 (RHOT * EMETH * EMETH) **.16666 - 77 * C9 * TFP /
      2 (RHOT * EMETH * EMETH / (RHOF * EMEF * EMEF))** .16666
7102   CONTINUE
       TFS = T(7)
       DOAXP = .75 * DIINP + 2.0 * TTP
       DOAXS = .75 * DIINS + 2.0 * TTP
       WBRIX = .08333 * EN * (2.0 * WINA + DOAXP)
       DOSC = DISC + 2.0 * TTP
       EMT = .00545 * RHOT * (ELCP * EN * (DOAXP*DOAXP-DIAVP*DIAVP)  +
      1 ELCS * (DOAXS*DOAXS-DIAVS*DIAVS) + ELSCS *(DOSC*DOSC-DISC*DISC))
       EMF = .00694 * RHOF * (ELCP * TFP * (C8 * WBRIX * 12. + 2.0 * EN
      1 * (1.0 - C8) * WINA) + ELTS *TFS * (C8 * (2.0 * WINS + DOAXS) +
      2 2.0 * (1.0 - C8) * WINS))
       EMIF = .0833 * ELCP * RHIF * TIF * WBRIX
       EMHS = .00545 * RHOH * WBRIX * ((DIHA+2.*TH)*(DIHA+2.*TH) - DIHA
      1 * DIHA + (DEHA +2.*TH)*(DEHA +2.*TH) - DEHA * DEHA)
       EMLI = .00545 * DISC * DISC * RHOL * ELSCS
       EMCR = EMT + EMF + EMIF + EMHS + EMLI
       ACRP = WBRIX * ELCP
       ACRS = .0833 * ELTS * (DOAXS + 2. * WINS)
```

FIGURE D-6 (cont'd)

```
      DIINH = 1,414 * DIHA
      DIEHE = 1,414 * DEHA
      FEFP = 17,5E+8 * QFTP / (EN * ELCP * FF * Z2 * WINA *
     1 (T12*T12*T12*T12- TS4(NUMBR)))
      DIEP = ,354 * DIINP
      WRITE (ITP2,3332)
 3332 FORMAT(//)
      WRITE (ITP2,3000)          DIINP,EN,WINA,VIN,DIINH,WBRIY,DPIH,
     1 DIFHE,DPEH,TTP,ELCP,DPLCP,DIEP,FEFP,TFP,DIINS,ELCS,DPLCS,ELSCS,
     2 ELT,TFS,WINS,DISC,QTOTP,QTOTS,QSC,EMT,EMF,EMIF,EMHS,EMLI,
     3 EMCR,ACRP,ACRS,ENUE
 3000 FORMAT(10X5HDIINP14X1HN11X4HWINA12X3HVIN10X5HDIINH10X5HWBRIY11X4HD
     1PIH10X5HDIEHE/,11X4HINCH26X4HINCH9X6HFT/SEC11X4HINCH13X2HFT12X3HPS
     2I11X4HINCH /,8F15.5/ ,11X4HDPEH12X3HTTP12X3HLCP10X5HDPLCP11X4HDIEP
     311X4HFEFP12X3HTFP10X5HDIINS/,12X3HPSI11X4HINCH13X2HFT12X3HPSI11X4H
     4INCH26X4HINCH11X4HINCH/ ,8F15.5/ ,12X3HLCS10X5HDPLCS11X4HLSCS13X2H
     5LT12X3HTFS11X4HWINS11X4HDISC10X5HQTOTP/,13X2HFT12X3HPSI13X2HFT13X
     62HFT,3(11X4HINCH),11X4HB/HR/ ,8F15.5/ ,10X5HQTOTS12X3HQSC13X2HMT
     713X2HMF12X3HMIF12X3HMHS12X3HMLI12X3HMCR/,11X4HB/HR11X4HB/HR,6(12X
     8 3HLBS),/ ,8F15.5/ ,11X4HACRP11X4HACRS12X3HNUF/,10X5HSQ FT10X5HSQ
     9FT6X9HNO OF G,S/ ,3F15,5//)
 89   IF(WINAH - WINA) 91, 91 ,90
 90   WINA = WINA + WINAD
      GO TO 12
 91   IF(ENH - EN) 93, 93, 92
 92   EN = EN + ENDEL
      GO TO 4
 93   IF(DINPH - DIINP)400, 400, 94
 94   DIINP = DIINP + DINPD
      GO TO 3
 400  CONTINUE
      GO TO 1
      END
      SUBROUTINE TABLE
      DIMENSION CCC(9,3)  ,ZZZ(9,5) ,C(9) , Z(9),DERIV( 8, 7),DELTA( 7)
      COMMON  N, J55,  IHALT, INDXS,
     1 DERIV, DELTA, C, Z, Y1, Y2, Y3, Y4
     2 ,ITP1,ITP2
C     CREATE RADIATOR INPUT TABLE
C     PROGRAM CONSTANTS - SELECTION
      DATA CCC,ZZZ/3*1,0,3*0,0,1,,2*0,0,1.125,.5,,75,0,,2*1.,,82,1,,,25,
     1.75,1.,1.5,0,,2,,2*0,,1.,,5,5*1.,0,,1.,0,,1,,1.,,5,0,,2*1.,0,,4,,2
     2*1.,1.5,3*.866,1,,0,,1.,0,,3,,2,,3*.707,1.,0,,1.,0,,4.,1.,,5,0,,1.
     3,0,,1.,4.,1,,1./
      READ (ITP1,1002) I,J,K,L
 1002 FORMAT(4I1)
      WRITE           ( ITP2,1005)I,J,K,L
 1005 FORMAT(/8H PUNT IS 2X4I1/)
      CCC(4,1) = 0,5
      DO  1   I1  = 1,9
      C(I1)  =  CCC(I1,I)
 1    Z(I1)  =  ZZZ(I1,J)
      GO TO (16,15,16,16,15),J
 15   Z(3) = C(4)
```

FIGURE D-6 (cont'd)

```
16     CONTINUE
       IF(K-1) 2 , 2 , 3
2      Y1 = 1.
       Y2 = 0.
       GO TO 4
3      Y1 =  0.
       Y2 =  1.
4      IF(L - 1)   5 , 5 , 6
5      Y3 = 1.
       Y4 = 0.
       RETURN
6      Y3 = 0.
       Y4 = 1.
       RETURN
       END
       SUBROUTINE CROUT
       DIMENSION A( 8, 7), H( 7)
       COMMON  N, J55,  IHALT, INDXS, A, H
       N1=N+1
       DO 200 K=1,N
       K1=K+1
       J=K
       DO 100 I=K,N
       SUM=0.0
       IF(J-1)10,13,10
   10  IF(I-1)13,13,11
   11  IF(I-J)17,17,21
   17  ISMX=I-1
       DO 12 IS=1,ISMX
   12  SUM=SUM+A(IS,I)*A(I,IS)
   13  A(J,I)=A(J,I)-SUM
       GO TO 100
   21  JSMX=J-1
       DO 22 JS=1,JSMX
   22  SUM=SUM+A(JS,I)*A(J,JS)
   23  A(J,I)=A(J,I)-SUM
  100  CONTINUE
       I=K
       DO 200 J=K1,N1
       SUM=0.0
       IF(I-1)233,233,231
  231  ISMX=I-1
       DO 232 IS=1,ISMX
  232  SUM=SUM+A(IS,I)*A(J,IS)
  233  IF(A(I,I))350,351,350
```

FIGURE D-6 (cont'd)

```
  351 A(J,I)=0.0
      GO TO 200
  350 A(J,I)=(A(J,I)-SUM)*(1./A(I,I))
  200 CONTINUE
C     HAVE COMPLETED FINDING THE DERIVED MATRIX
      DO 300 IS=1,N
      SUM=0.0
      JS=N-IS+1
      JS1=JS+1
      DO 280 KS=JS1,N
      IF(KS-N)280,280,300
  280 SUM=SUM+A(KS,JS)*H(KS)
  300 H(JS)=A(N1,JS)-SUM
      J55=J55+1
      IF(20-J55) 302,302,303
302   IHALT = 99
      INDXS = 2
  303 RETURN
      END
```

FIGURE D-6 (cont'd)

COMPUTER FLOW CHART - FUEL CELL PERFORMANCE PROGRAM

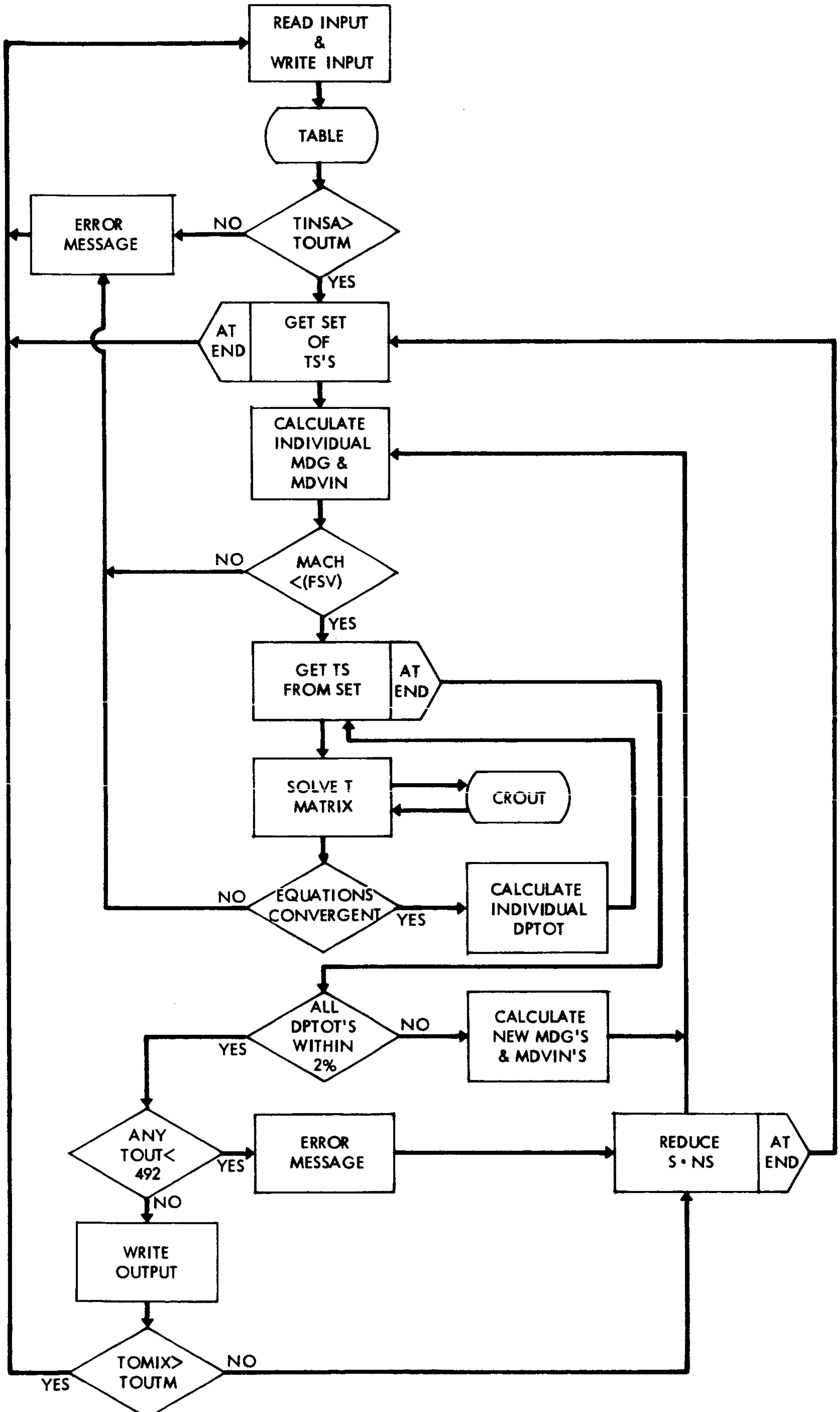

Figure D-7

SOURCE DECK PRINTOUT
FUEL CELL PERFORMANCE PROGRAM

```
      DIMENSION QIS(12), QIT(12), TS4(12), TS(12),             FNUE(12),
     1 TOU(12), AMDT(12),AMDG(12),AMVI(12),    DPTOT(12),
     2 CNST(21),GTS(12),QFS(12),PSA(3),EMDV(3),RM(3),ROM(3),TSH(3),VM(3)
     3,RE(3),WEF(3),RF(3),TSTOR(3),PHI(3),FR(3),DR(3),            AMTC(12),
     4 AMVE(12),DERIV(22,21),DELTA(21) , T(21), T3(21),STOR(16)
     5,XTS(12,12),XQIS(12,12),XQIT(12,12),TITLE(16),INTSX(12)
      COMMON N, J55, IHALT, INDXS, DERIV, DELTA,C1,C2,C3,C4,C5,C6,C7,C8,
     1 C9,Z1,Z2,Z3,Z4,Z5,Z6,Z7,Z8,Z9, Y1,Y2,Y3,Y4,ITP1,ITP2
      N = 21
      ITP1 = 5
      ITP2 = 6
      WRITE (ITP2,1002)
 1002 FORMAT(60H PERFORMANCE ANALYSIS PROGRAM,H2 - H2O FUEL CELL, DIRECT
     1 R/C   ,/)
  600 READ (ITP1,1005) TITLE
 1005 FORMAT(16A5)
      WRITE (ITP2,1005) TITLE
      READ (ITP1,9347) NSETS
 9347 FORMAT(I2)
      DO 9348 J=1,NSETS
      READ (ITP1,9347) INTSX(J)
      K=INTSX(J)
 9348 READ (ITP1,9349) (XTS(I,J), XQIS(I,J), XQIT(I,J), I=1,K)
 9349 FORMAT(3F10.4)
      READ (ITP1,1000)          EN,S,DIIN,DOIN,WBAR1,WBARE,TFIN,TFOUT,
     1         TOLTM,     PM,ALPHS,ALPHT,EKTH,EKF,ET,EF,FSV,ELC,EMDTG,EMDG,
     2 EMDVN,TIN,SHIN
 1000 FORMAT(8F10.4)
      CALL TABLE
```

FIGURE D-8

```
      WRITE (ITP2,1003)        EN,S,DIIN,DOIN,WBAR1,WBARE,TFIN,TFOUT,
     1      TOUTM,     PM,ALPHS,ALPHT,EKTH,EKF,ET,EF,FSV,ELC,EMDTG,EMDG,
     2 EMDVN,TIN,SHIN
 1003 FORMAT(14X1HN14X1HS11X4HDIIN11X4HDOIN10X5HWBAR110X5HWBARE11X4HTFIN
     110X5HTFOUT/41X4HINCH11X4HINCH13X2HFT13X2HFT11X4HINCH11X4HINCH/,8F
     2 15.5//10X5HTOUTM13X2HPM10X5HALPHS10X5HALPHT12X3HKTH13X2HKF13X2HET
     313X2HEF/10X5HDEG R11X4HPSIA36X9HB/HR FT F6X9HB/HR FT F/8F15.5//
     412X3HFSV13X2HLC11X4HMDTG12X3HMDG10X5HMDVIN12X3HTIN13X4HSHIN/
     528X2HFT8X7HLBS/MIN8X7HLBS/MIN8X7HLBS/MIN10X5HDEG R/7F15.5// )
      DO 601 ITIME =1,NSETS
      INTS = INTSX(ITIME)
      DO 9350 I=1,INTS
      TS(I) = XTS(I,ITIME)
      QIS(I)=XQIS(I,ITIME)
 9350 QIT(I)= XQIT(I,ITIME)
      IF(EMDG) 27, 24, 27
 24   IF(EMDTG) 26 , 25 , 26
 25   WRITE (ITP2,2000)
 2000 FORMAT(26HBOTH MDG AND MDTG ARE ZERO)
      GO TO 600
 26   EMDG = EMDTG / (1.0 + SHIN)
      EMDVN = EMDTG - EMDG
 27   PINSA = PM * EMDVN / (9.06 * EMDG + EMDVN)
      TINSA = 562.0 + 39.51 *ALOG (PINSA)
      IF(TINSA - TOUTM) 4,4,5
 4    WRITE (ITP2,2002) TINSA
 2002 FORMAT(6H TINSA,F15.8,16H LESS THAN TOUTM )
      GO TO 600
 5     ENS = 1.0
      DO 61 I = 1,INTS
      IF(TS(I))  28, 51, 51
 28   TS4(I) = 5.83E+08 * (QIS(I) * ALPHS / ALPHT + QIT(I))
      TS(I) = TS4(I) ** 0.25
      GO TO 61
 51   TS4(I) = TS(I) ** 4.0
 61   CONTINUE
      EE = 2.7182818
      WIN = 0.5 * (12.0 * WBAR1 / EN - DOIN)
      WOUT = 0.5 * (12.0 * WBARE / EN - DOIN)
      W1 =.166667* (5.0 * WIN + WOUT)
      W2 = 0.5 * (WIN + WOUT)
      W12 = 0.5 * (W1 + W2)
      W3 =.166667* (WIN + 5.0 * WOUT)
      W23 = 0.5 * (W2 + W3)
      TF1 =.166667* (5.0 * TFIN + TFOUT)
      TF2 = 0.5 * (TFIN + TFOUT)
      TF12 = 0.5 * (TF1 + TF2)
      TF3 =.166667* (TFIN + 5.0 * TFOUT)
      TF23 = 0.5 * (TF2 + TF3)
      IF(C5) 16, 13, 16
 13   STORE = DOIN / (WIN + WOUT)
      F1SP = 1.0 + 2.0 / STORE
      F1SP = ATAN (SQRT (F1SP * F1SP - 1.0)) / 2.0
      F1SP = 0.6366*(1.+(1./STORE  * (1.0 - SQRT (1.0 + STORE)) + F1SP))
      F3SP = SQRT (.1 * STORE + 0.0025) / (2.0 * STORE + 0.1) + SQRT
     1 (3.9 * STORE + 3.803) / (2.0 * STORE + 3.9)
      F4SP = SQRT (.4 * STORE + 0.04) / (2.0 * STORE + 0.4) + SQRT
     1 (3.6 * STORE + 3.24) /  (2.0 * STORE + 3.6)
```

FIGURE D-8 (cont'd)

```
      F5SP = SQRT (0.9 * STORE + 0.2025) / (2.0 * STORE + 0.9) + SQRT
     1 (3.1 * STORE + 2.403) / (2.0 * STORE + 3.1)
      F6SP = SQRT (1.6 * STORE + 0.64) / (2.0 * STORE + 1.6) + SQRT
     1 (2.4 * STORE + 1.44) / (2.0 * STORE + 2.4)
16    IF(C5-1.0) 21,17 ,21
17    IF(73) 18 , 22, 18
18    STORE = DOIN / WIN
      F1SP = 0.3183 * (ATAN (1.0 + 4.0 / STORE) + 0.2146)
      F3SP = (0.05 * STORE + 0.0025) / (0.005 + 0.1 * STORE +STORE*STORE
     1 ) + (1.95 * STORE + 3.803) / (7.606 + 3.9 * STORE + STORE*STORE)
      F4SP = (0.2 * STORE + 0.04) / (0.08 + 0.4 * STORE + STORE * STORE)
     1 + (1.8 * STORE + 3.24) / (6.48 + 3.6 * STORE + STORE * STORE)
      F5SP = (0.45 * STORE + 0.2025) / (0.405 + 0.9 * STORE+STORE*STORE)
     1 + (1.55* STORE + 2.403) / (4.806+3.1*STORE+STORE*STORE)
      F6SP = (0.8 * STORE + 0.64) / (1.28 + 1.6*STORE + STORE*STORE)
     1 + (1.2* STORE + 1.44) / (2.88 + 2.4*STORE + STORE*STORE)
21    IF(C5-2.0) 64, 22, 64
22    F1SP = 1.0
      F3SP = 1.0
      F4SP = 1.0
      F5SP = 1.0
      F6SP = 1.0
64    DO 65 I=1,INTS
65    AMDT(I) = (EMDG + EMDVN) / (EN * ENS)
      IDP = 0
77    DO 89 I =1,INTS
      AMDG(I) = AMDT(I) * EMDG / ( EMDG + EMDVN)
      AMVI(I) = AMDT(I) - AMDG(I)
      ERM          = (776.0 * AMDG(I)      + 85.6 * AMVI(I)      ) /
     1   (AMDG(I)       + AMVI(I)      )
      EROM= 144.0 * PM / (TIN *ERM)
      EVM= 3.06 * (AMDG(I)       + AMVI(I)      ) / (EROM *
     1 DIIN * DIIN )
      SOVV = 6.72 * SQRT (ERM* TIN)
      IF(EVM-ESV*SOVV) 89,89,99
99    WRITE (ITP2,2001)
2001  FORMAT(/18H MACH NO. TOO HIGH  /)
      GO TO 601
89    CONTINUE
      DO 400 NUMBR = 1,INTS
      ERM          = (776.0 * AMDG(NUMBR) + 85.6 * AMVI(NUMBR)) /
     1   (AMDG(NUMBR) + AMVI(NUMBR))
      EROM= 144.0 * PM / (TIN *ERM)
      EVM= 3.06 * (AMDG(NUMBR) + AMVI(NUMBR)) / (EROM *
     1 DIIN * DIIN )
      IF(NUMBR-1) 92,92,90
90    IF(TS(NUMBR)-TS(NUMBR-1))92,91,92
91    I=NUMBR-1
      TOU(NUMBR)=TOU(I)
      QTS(NUMBR)=QTS(I)
      QES(NUMBR)=QES(I)
      AMVE(NUMBR)=AMVE(I)
      DPTOT(NUMBR)=DPTOT(I)
      ENUE(NUMBR)=ENUE(I)
      GO TO 400
92    ILOOP = 0
      DO 101 I = 1,21
      AI = I
```

FIGURE D-8 (cont'd)

```
      T(I) = TINSA - 3.0 * AI
 101  T3(I) = T(I) * T(I) * T(I)
      IF(TS(NUMBR)-TINSA) 3,2,2
 2    TOU(NUMBR) = TINSA
      TSTOR(1) = TINSA
      TSTOR(2) = TINSA
      TSTOR(3) = TINSA
      EMDV(1) = AMVI(NUMBR)
      EMDV(2) = AMVI(NUMBR)
      EMDV(3) = AMVI(NUMBR)
      AMVE(NUMBR) =AMVI(NUMBR)
      QTS(NUMBR) = 0.0
      QFS(NUMBR) = 0.0
      ILOOP = -1
      GO TO 105
 3    BETA1 = 1.0 + 0.45 * (TIN - TINSA) / (TINSA - 625.0)
 62   BETA2 = 2.22 * BETA1 - 1.22
      INDXS = 1
      STOR(1) = BETA2*AMDG(NUMBR)*3.42 + AMVI(NUMBR)*BETA1
 C    THE 1.15 IN THE NEXT EQ. IS THE CORR. TO THE THEORET. HT.LOSS EQ.
      STOR(2)=1.15 * AMDG(NUMBR)*106200./PM**1.112
      STOR(3) = DIIN * ELC * 1.394 /(0.024 +(DOIN - DIIN)/EKTH)
      STOR(4) = (DOIN*DOIN - DIIN*DIIN)* EKTH / ELC
      STOR(5) = (DOIN - DIIN) * EKTH * ELC / (DOIN + DIIN)
      STOR(6) = 1.495E-10 * F1SP * Z3 * C7 * DOIN * ELC * ET
      STOR(7) = TF1 * ELC * EKF / W1
      STOR(8) = 0.238E-10 * Z4 * C5 * EF * DOIN * ELC
      STOR(9) = W12 * TF12 * EKF / ELC
      STORE = Z2 * C2 * EF * ELC * W1
      STOR(10) = STORE * (C6 + F3SP) * 0.95E-11
      STOR(11) = STORE * (C6 + F4SP) * 1.9E-11
      STOR(12) = STORE * (C6 + F5SP) * 2.85E-11
      STOR(13) = STORE * (C6 + F6SP) * 3.8E-11
      STOR(14) = TF2 * ELC * EKF / W2
      STOR(15) = W23 * TF23 * EKF / ELC
      STOR(16) = TF3 * ELC * EKF / W3
      CNST(1) = 60.0*STOR(1)*TINSA + STOR(2)*FE**(.0237*(TINSA-460.0))
      CNST(2) = TS4(NUMBR) * STOR(6)
      CNST(3) = TS4(NUMBR) * STOR(8)
      CNST(4) = TS4(NUMBR) * STOR(10)
      CNST(5) = TS4(NUMBR) * STOR(11)
      CNST(6) = TS4(NUMBR) * STOR(12)
      CNST(7) = TS4(NUMBR) * STOR(13)
      CNST(8) = 0.0
      CNST(9) = CNST(2)
      CNST(10)= CNST(3)
      CNST(11)= CNST(4)
      CNST(12)= CNST(5)
      CNST(13)= CNST(6)
      CNST(14)= CNST(7)
      CNST(15)= 0.0
      CNST(16)= CNST(2)
      CNST(17)= CNST(3)
      CNST(18)= CNST(4)
      CNST(19)= CNST(5)
      CNST(20)= CNST(6)
      CNST(21)= CNST(7)
      J55 = 0
```

FIGURE D-8 (cont'd)

```
100   CONTINUE
      DO 208 I = 1,21
      DO 208 J = 1,22
208   DERIV(J,I) = 0,0
      DERIV(1,1) =-30.0*STOR(1) - STOR(2)*EE**(.01185*(T(1)+T(8)-920.))
     1 * .01185 - C1 * STOR(3) - C3 * STOR(3) / 2.0
      DERIV(2,1) = C1 * STOR(3)
      DERIV(3,1) = C3 * STOR(3) / 2.0
      DERIV(8,1) =-30.0*STOR(1) - STOR(2)*EE**(.01185*(T(1)+T(8)-920.))
     1 * .01185
      DERIV(1,2) = C1 * STOR(3)
      DERIV(2,2) = - C1 * STOR(3) - .0109 * C1 * STOR(4) - 1.7 * C2 *
     1 STOR(5) - 4.0 * STOR(6) * T3(2)
      DERIV(3,2) = 1.7 * C2 * STOR(5)
      DERIV(9,2) = .0109 * C1 * STOR(4)
      DERIV(1,3) = C3 * STOR(3) / 4.0
      DERIV(2,3) = 0.85 * C2 * STOR(5)
      DERIV(10,3)= .002722 * C3 * STOR(4)
      DERIV(4,3) = 6.67 * STOR(7)
      DERIV(3,3) = -DERIV(1,3) -DERIV(10,3) - DERIV(2,3) - DERIV(4,3)
     1 - 4.0 * STOR(8) * T3(3)
      DERIV(3,4) = DERIV(4,3)
      DERIV(11,4)= .002085 * STOR(9)
      DERIV(5,4) =  2.22 * STOR(7)
      DERIV(4,4) = -DERIV(3,4) -DERIV(11,4) -DERIV(5,4) -4.0*STOR(10) *
     1 T3(4)
      DERIV(4,5) = DERIV(5,4)
      DERIV(12,5)= .00417 * STOR(9)
      DERIV(6,5) = 1.334 * STOR(7)
      DERIV(5,5) = -DERIV(4,5) -DERIV(12,5) - DERIV(6,5)-4.0*STOR(11) *
     1 T3(5)
      DERIV(5,6) = DERIV(6,5)
      DERIV(13,6)= .00624 * STOR(9)
      DERIV(7,6) = .952 * STOR(7)
      DERIV(6,6) = -DERIV(5,6) -DERIV(13,6) - DERIV(7,6) - 4.0 *STOR(12)
     1 * T3(6)
      DERIV(6,7) = DERIV(7,6)
      DERIV(14,7)=  .00834 * STOR(9)
      DERIV(7,7) = -DERIV(6,7) -DERIV(14,7) - 4.0 * STOR(13) * T3(7)
      DERIV(1,8) = 30. * STOR(1) + STOR(2) * EE**(.01185*(T(1) + T(8) -
     1  920.))  * .01185
      DERIV(9,8) = DERIV(2,1)
      DERIV(10,8)= DERIV(3,1)
      DERIV(8,8) =-10. * STOR(1) + STOR(2) *EE**(.01185*(T(1)+T(8)-920.)
     1 ) * .01185 - STOR(2)*EE**(.00790*(2.0*T(8)+T(21)-1380.)) *.00790
     2 -DERIV(9,8) -DERIV(10,8)
      DERIV(21,8) =-20. * STOR(1) - STOR(2)*EE**(.00790 *(2.*T(8)  +
     1 T(21) -1380.)) * .00790
      DERIV(8,9) = DERIV(2,1)
      DERIV(2,9) = DERIV(9,2)
      DERIV(15,9)= DERIV(2,9)
      DERIV(10,9)= DERIV(3,2)
      DERIV(9,9) = -DERIV(8,9) -DERIV(2,9) - DERIV(15,9) - DERIV(10,9)
     1 - 4.0 * STOR(6) * T3(9)
      DERIV(8,10) = DERIV(3,1)  / 2.0
      DERIV(3,10) = DERIV(10,3)
      DERIV(16,10)= DERIV(3,10)
      DERIV(9,10) = DERIV(2,3)
```

FIGURE D-8 (cont'd)

```
      DERIV(11,10)= 6.67 * STOR(14)
      DERIV(10,10)= -DERIV(8,10) - DERIV(3,10) - DERIV(16,10) - DERIV(9,
     1 10) - DERIV(11,10) - 4.0 * STOR(8) * T3(10)
      DERIV(10,11)= DERIV(11,10)
      DERIV(4,11) = DERIV(11,4)
      DERIV(17,11)= .002085 * STOR(15)
      DERIV(12,11)= 2.22 * STOR(14)
      DERIV(11,11) = -DERIV(10,11) -DERIV(4,11) -DERIV(17,11)-DERIV(12,
     1 11) - 4.0 * STOR(10) * T3(11)
      DERIV(11,12) = DERIV(12,11)
      DERIV(13,12) = 1.334 * STOR(14)
      DERIV(5,12)  = DERIV(12,5)
      DERIV(18,12) = .00417 * STOR(15)
      DERIV(12,12) = -DERIV(11,12) - DERIV(13,12) -DERIV(5,12) -
     1 DERIV(18,12) - 4.0 * STOR(11) * T3(12)
      DERIV(12,13) = DERIV(13,12)
      DERIV(14,13) = .952 * STOR(14)
      DERIV(6,13) = .00624 * STOR(9)
      DERIV(19,13)= .00624 * STOR(15)
      DERIV(13,13)= -DERIV(12,13) - DERIV(14,13) - DERIV(6,13) -
     1 DERIV(19,13) - 4.0 * STOR(12) * T3(13)
      DERIV(13,14) = DERIV(14,13)
      DERIV(7,14) =  DERIV(14,7)
      DERIV(20,14) = .00834 * STOR(15)
      DERIV(14,14) = -DERIV(13,14) -DERIV(7,14) -DERIV(20,14) -
     1 4.0 * STOR(13) * T3(14)
      DERIV(15,15) = DERIV(2,1)
      DERIV(16,15) = DERIV(3,1)
      DERIV(8,15) = 40. * STOR(1) + STOR(2) * EE**(.00790 *(2.0*T(8) +
     1 T(21)-1380.))*.00790 -
     2   DERIV(15,15)/3.0 - DERIV(16,15)/3.0
      DERIV(21,15) =-40.0 * STOR(1) + STOR(2) * EE**(.00790*(2.0 * T(8)
     1     + T(21)   -1380.)) * .00790 -
     2 STOR(2) * EE**(.0237 *(  T(21)    -460.))*.0237
     3 - 2.0 / 3.0 * ( DERIV(15,15) + DERIV(16,15) )
      DERIV(8,16) = DERIV(2,1) / 3.0
      DERIV(21,16)= 2.0 * DERIV(8,16)
      DERIV(9,16) = DERIV(9,2)
      DERIV(16,16) = DERIV(3,2)
      DERIV(15,16) =-DERIV(2,1) - DERIV(16,16) -DERIV(9,16) -
     1 4.0 * STOR(6) * T3(15)
      DERIV(8,17) = DERIV(3,1) / 6.0
      DERIV(21,17)= DERIV(8,17) * 2.0
      DERIV(10,17)= DERIV(10,3)
      DERIV(15,17)= DERIV(2,3)
      DERIV(17,17) = 6.67 * STOR(16)
      DERIV(16,17) = -DERIV(8,17) * 3.0 -DERIV(10,17) - DERIV(15,17)
     1 -DERIV(17,17) - 4.0 * STOR(8) * T3(16)
      DERIV(16,18) = DERIV(17,17)
      DERIV(11,18) = DERIV(17,11)
      DERIV(18,18) = 2.22 * STOR(16)
      DERIV(17,18) = -DERIV(16,18) -DERIV(11,18) -DERIV(18,18) -
     1 4.0 * STOR(10) * T3(17)
      DERIV(17,19) = DERIV(18,18)
      DERIV(19,19) = 1.334 * STOR(16)
      DERIV(12,19) = DERIV(18,12)
      DERIV(18,19) = -DERIV(17,19) -DERIV(19,19) -DERIV(12,19) -
     1 4.0 * STOR(11) * T3(18)
```

FIGURE D-8 (cont'd)

```
      DERIV(18,20) = DERIV(19,19)
      DERIV(20,20) = .952 * STOR(16)
      DERIV(13,20) = DERIV(19,13)
      DERIV(19,20) = -DERIV(18,20) -DERIV(20,20) -DERIV(13,20) -
     1 4.0 * STOR(12) * T3(19)
      DERIV(19,21) = DERIV(20,20)
      DERIV(14,21) = DERIV(20,14)
      DERIV(20,21) = -DERIV(19,21) -DERIV(14,21) - 4.0 * STOR(13)*T3(20)
      DERIV(22,1) = CNST(1) + 30. * STOR(1) *(-T(1)-T(8))  - STOR(2) *
     1 EE ** (.01185 * (T(1) + T(8) - 920.)) -STOR(3) *(C1*(T(1)-T(2))
     2 + C3 / 2.0 * (T(1) - T(3)))
      DERIV(22,2) = C1*STOR(3)*(T(1)-T(2)) - 0.0109 * C1 * STOR(4) *
     1 (T(2)-T(9)) - 1.7 * C2 * STOR(5) * (T(2)-T(3)) - STOR(6) * T3(2)
     2 * T(2) + CNST(2)
      DERIV(22,3) = CNST(3) + C3 * STOR(3) / 4.0 * (T(1) - T(3))
     1 - .002722 * C3 * STOR(4) * (T(3) - T(10)) + 0.85 * C2 * STOR(5)
     2 * (T(2) - T(3)) - 6.67 * STOR(7) * (T(3) - T(4)) - STOR(8) *
     3 T3(3) * T(3)
      DERIV(22,4) = CNST(4) + 6.67 * STOR(7) * (T(3)-T(4)) -.002085 *
     1 STOR(9) * (T(4)-T(11)) -2.22 * STOR(7) *(T(4)-T(5)) - STOR(10)*
     2 T3(4) * T(4)
      DERIV(22,5) = CNST(5) + 2.22 * STOR(7) * (T(4)-T(5)) -.00417 *
     1 STOR(9) * (T(5)-T(12)) -1.334*STOR(7) * (T(5)-T(6)) - STOR(11)
     2 * T3(5) * T(5)
      DERIV(22,6) = CNST(6) + STOR(7)* (1.334 *(T(5)-T(6)) -.952 *
     1 (T(6) - T(7))) -.00624 * STOR(9) * (T(6)- T(13))-STOR(12) *
     2 T3(6) * T(6)
      DERIV(22,7) = CNST(7) + .952 * STOR(7) * (T(6)-T(7))- .00834 *
     1 STOR(9) * (T(7)-T(14)) - STOR(13) * T3(7) * T(7)
      DERIV(22,8) = CNST(8) + 10. * STOR(1) * (3.* T(1) - 2.*T(21)
     1 -T(8)) + STOR(2)*EE**(.01185*(T(1)+T(8)-920.))-STOR(2)*EE**
     2 (.00790*(2.*T(8)+T(21)      -1380.))- STOR(3)*(C1*(T(8)-T(9)) +
     3 C3 /2. * (T(8)- T(10)))
      DERIV(22,9) = CNST(9) + C1*STOR(3)*(T(8)-T(9)) +.0109*C1*STOR(4)
     1 *(T(2) -2.*T(9) + T(15)) -1.7*C2*STOR(5)*(T(9)-T(10)) -STOR(6)
     2 * T3(9) * T(9)
      DERIV(22,10) = C3 /4.0 * STOR(3) *(T(8)- T(10)) +.002722 * C3 *
     1 STOR(4) * (T(3) - 2. * T(10) + T(16)) + .85 * C2 * STOR(5) *
     2 (T(9)-T(10))-6.67*STOR(14)*(T(10)-T(11))-STOR(8)*T3(10)*T(10) +
     3 CNST(10)
      DERIV(22,11) = CNST(11) + 6.67 * STOR(14) * (T(10)-T(11)) +.002085
     1 * STOR(9) * (T(4)-T(11)) -.002085 * STOR(15)*(T(11)-T(17)) - 2.22
     2 * STOR(14)* (T(11)-T(12)) - STOR(10) * T3(11) * T(11)
      DERIV(22,12) = CNST(12) + 2.22 * STOR(14) * (T(11)-T(12)) - 1.334
     1 * STOR(14)* (T(12)-T(13)) + .00417 * STOR(9) * (T(5)-T(12))
     2 - STOR(11) * T3(12)*T(12) -.00417*STOR(15)*(T(12)-T(18))
      DERIV(22,13) = 1.334 * STOR(14) * (T(12)-T(13)) -.952 * STOR(14)
     1 * (T(13)-T(14)) +.00624 * STOR(9) * (T(6)-T(13)) -.00624 *
     2 STOR(15) * (T(13) - T(19)) - STOR(12) * T3(13) * T(13) + CNST(13)
      DERIV(22,14) = CNST(14) + .952 * STOR(14) * (T(13)-T(14))+.00834
     1 * STOR(9) * (T(7)-T(14)) -.00834 * STOR(15) * (T(14)-T(20))
     2 - STOR(13) * T3(14) * T(14)
      DERIV(22,15) = STOR(1) * 40.0 * (T(8) - T(21)   )    + STOR(2) *
     1 EE**(.00790 * (2.*T(8) + T(21)      -1380.))-STOR(2)*EE**(.0237*
     2 (T(21)     -460.))- C1 * STOR(3) / 3.0  * (2.*T(21)      +T(8)-
     3 3.0*T(15)) - C3 * STOR(3) / 6.0 * (2.*T(21)      +T(8)-3.*T(16))
      DERIV(22,16) = CNST(16) + C1 * STOR(3) / 3.0*(2.*T(21)+T(8)-3. *
     1 T(15)) +.0109 * C1 * STOR(4) * (T(9)-T(15)) -1.7 * C2 * STOR(5)
```

FIGURE D-8 (cont'd)

```
     2 * (T(15)-T(16)) - STOR(6) * T3(15) * T(15)
      DERIV(22,17) = CNST(17) + C3 * STOR(3) /12. * (2.*T(21)       +T(8)
     1 - 3.*T(16)) +.002722 * C3 * STOR(4) * (T(10)-T(16)) +.85 * C2
     2 * STOR(5) * (T(15)-T(16)) - 6.67 * STOR(16) * (T(16)-T(17))
     3 - STOR(8) * T(16) * T3(16)
      DERIV(22,18) = CNST(18) + 6.67 * STOR(16) * (T(16) - T(17))
     1 +.002085 * STOR(15)* (T(11) - T(17)) - 2.22 * (T(17)-T(18))
     2 - STOR(10) * T3(17) * T(17)
      DERIV(22,19) = CNST(19) + 2.22 * STOR(16) * (T(17)-T(18)) -1.334
     1 * STOR(16) * (T(18)-T(19)) +.00417 * STOR(15) * (T(12)-T(18))
     2 - STOR(11) * T3(18) * T(18)
      DERIV(22,20) = CNST(20) + 1.334 * STOR(16) * (T(18)-T(19)) -.952
     1 * STOR(16) * (T(19) - T(20)) +.00624 * STOR(15) * (T(13)-T(19))
     2 - STOR(12) * T3(19) * T(19)
      DERIV(22,21) = CNST(21) + .952 * STOR(16) * (T(19)-T(20)) -.00834
     1 * STOR(15) * (T(14)-T(20))-STOR(13)*T3(20)*T(20)
      DO 104 I=1,21
  104 DERIV(22,I) = -DERIV(22,I)
      CALL CROUT
      GO TO(201,200),INDX5
  200 WRITE (ITP2,2003)
 2003 FORMAT(/33H 20 CYCLES--MATRIX NOT CONVERGED   /)
      GO TO 601
  201 STORE = 0.0
      DO 203 I = 1,21
      T(I) = T(I) + DELTA(I)
  207 T3(I) = T(I) * T(I) * T(I)
      IF(ABS (DELTA(I))-STORE) 203,203,205
  205 STORE = ABS (DELTA(I))
  203 CONTINUE
      IF(STORE-1.0) 206, 206, 100
  206 TOU(NUMBR) = T(21)
      BETIC = 1.0 + 0.45 * (TIN - TINSA) / (TINSA - TOU(NUMBR))
      IF(ABS ((BETIC - BETA1) / BETIC) -.05) 103, 103, 102
  102 BETA1 = BETIC
      ILOOP = ILOOP + 1
      IF(ILOOP - 6) 62, 103, 103
  103 STORE = TOU(NUMBR)
      QTS(NUMBR) = (3.42*BETA2*AMDG(NUMBR)+BETA1*AMVI(NUMBR))*60.*EN/S
     1*(TINSA-STORE) + STOR(2) * EN/S
     2 * (EE**(0.0237*(TINSA-460.)) -EE**(0.0237*(STORE - 460.)))
      QFS(NUMBR)=0.
      DO 6100 J=1,3
      DO 6100 I=4,7
      ISUB=7*(J-1) + I
 6100 QFS(NUMBR)=QFS(NUMBR)+STOR(I+6)*(T3(ISUB)*T(ISUB)-
     1  TS4(NUMBR)) * 2. * EN/S
      TSTOR(1) = T(1)
      TSTOR(2) = T(8)
      TSTOR(3) = 0.667 * TOU(NUMBR) + 0.333 * T(8)
  105 DO 161 I = 1,3
      AI = 7 - 2 * I
      IF(ILOOP) 106,107,107
  107 PSA(I) = 6.658E-07*EE**(0.02531 * TSTOR(I))
      EMDV(I) = 9.06 * AMDG(NUMBR) / (PM / PSA(I) - 1.0)
  106 TSH(I) = TSTOR(I) + AI * (TIN - TINSA) / 6.0
      RM(I) = (776. * AMDG(NUMBR) + 85.6 * EMDV(I)) / (AMDG(NUMBR) +
     1 EMDV(I))
```

FIGURE D-8 (cont'd)

```
      ROM(I) = 144.0 * PM / (RM(I) * TSH(I))
      VM(I) = 3.06 * (AMDG(NUMBR) + EMDV(I)) / (ROM(I)*DIIN*DIIN)
      RE(I) = 11.8E+06 * ROM(I) * VM(I) * DIIN / (TSH(I) + 315.)
      WEF(I) = .11 * VM(I) * SQRT (ROM(I))*(AMVI(NUMBR)-EMDV(I)) / DIIN
      RF(I) = 2.83E+04 *(AMVI(NUMBR)-EMDV(I))/((683.-TSTOR(I))*DIIN)
      IF(RE(I) - 2000.) 153, 153, 154
153   FR(I) = 64.0 /  RE(I)
      GO TO 157
154   IF(RE(I) - 4000.) 155, 156, 156
155   FR(I) = 0.00277 * RE(I) ** (.322)
      GO TO 157
156   FR(I) = 0.316 / RE(I) ** (.25)
157   IF(RF(I) - 200.) 158, 158, 160
158   IF(WEF(I) - 3.)  159, 159, 160
159   STORE = (AMVI(NUMBR) - EMDV(I)     ) * (683. - TSTOR(I)) *
     1 ROM(I) / (FR(I) * RE(I) *(EMDV(I)+AMDG(NUMBR))*(TSH(I)+315.0))
      DR(I) = 12.93 * SQRT (STORE)
      IF(RE(I) - 2000.) 1592, 1592, 1594
1592  STORE = 1.0 + DR(I)
      PHI(I) = STORE*STORE*STORE*STORE
      GO TO 161
1594  PHI(I) = (0.5 + SQRT (0.25 + DR(I))) ** 4.75
      GO TO 161
160   PHI(I) = (AMDT(NUMBR) / (AMDG(NUMBR) + EMDV(I))) ** 0.75
161   CONTINUE
      DPC = 0.0
      DO 162 I = 1,3
162   DPC         = DPC         +PHI(I)*FR(I)*ROM(I)*VM(I)*VM(I)
      DPC = 4.31E-04 * ELC * DPC / DIIN
      IF(ILOOP) 211,210,210
210   PSE          = 6.658E-07 * EE ** (0.02531 * TOU(NUMBR))
      AMVE(NUMBR) = 9.06 * AMDG(NUMBR) / (PM / PSE -1.0 )
211   DPENT = 1.08E-04 * EROM * EVM * EVM
      DIHA = 0.5 * DIIN * SQRT (EN / (Z1 * S))
      DEHA = DIHA
      REIHA = 11.8E+06 * EROM  * DIHA * EVM  / (TIN + 315.)
      IF(REIHA - 4000.) 222, 221, 221
221   DPIH = 1.025E-04 * EROM * EVM * EVM    * WBAR1 / (S * DIHA * Z1
     1 * REIHA ** 0.25 )
      GO TO 225
222   IF(REIHA - 2000.) 223, 223, 224
223   DPIH = 2.08E-02 * EROM * EVM * EVM    * WBAR1 / (S * DIHA * Z1
     1 * REIHA)
      GO TO 225
224   DPIH = 0.899E-06 * EROM * EVM * EVM    * WBAR1 * REIHA ** 0.322 /
     1 (S * DIHA * Z1)
225   RME =(AMDG(NUMBR)*776.+AMVE(NUMBR)*85.6)/(AMDG(NUMBR)+
     1 AMVE(NUMBR) )
      ROME = 144. * PM / (RME * TOU(NUMBR))
      VME=3.05*(AMDG(NUMBR)+AMVE(NUMBR))/(ROME*DIIN*DIIN)
      REEHA = 11.8E+06 * ROME * DEHA * VME / (TOU(NUMBR)+315.0)
      IF(REEHA - 4000.) 228, 227, 227
227   DPEH = 1.025E-04 * ROME * VME * VME * WBARE / (S * DEHA * Z1 *
     1  REEHA ** .25 )
      GO TO 231
228   IF(REEHA - 2000.) 229, 229, 230
229   DPEH = 2.08E-02 * ROME * VME * VME * WBARE / (S * DEHA * Z1*REEHA)
      GO TO 231
```

FIGURE D-8 (cont'd)

```
230   DPEH = 0.899E-06 * ROME * VME * VME * WBARE * REEHA** 0.322  /
     1 (S * DEHA * Z1)
231   DPEX = 1.08E-04 * ROME * VME * VME
      DPMOM = 2.15E-04 *(FROM*EVM*EVM     - ROME*VME*VME)
      DPTOT(NUMBR) = DPIH + DPENT + DPC  + DPEX + DPEH - DPMOM
      REEN = 11.8E+06 * ROME * DIIN * VME  / (315. + TOU(NUMBR))
      STORE = (AMVI(NUMBR)-AMVE(NUMBR))*(683.0-TOU(NUMBR)) +1.E-30
      ENUE(NUMBR)=(DIIN/STORE)**0.333333 * (0.0825*ROME*VME*VME
     1 / REEN **0.25 + 0.1325*(AMVI(NUMBR)-AMVE(NUMBR))*VME/(DIIN*ELC))
400   CONTINUE
      DPTM = 0.0
      DO 214 I = 1,INTS
214   DPTM = DPTM + DPTOT(I)
      STORE = INTS
      DPTM = DPTM / STORE
      IDP = IDP + 1
      DO 163 I=1,INTS
      IF(ABS ((DPTM-DPTOT(I)      )/DPTM)-.02) 163,163,165
163   CONTINUE
      GO TO 164
165   IF(IDP-6) 168,164,164
168   EMDTC = 0.0
      DO 166 I=1,INTS
      AMTC(I) = DPTM * AMDT(I) / DPTOT(I)
166   EMDTC = EMDTC + AMTC(I)
      EMDTC = EMDTC * EN / S
      DO 167 I = 1,INTS
167   AMDT(I) = AMTC(I) * (EMDG+EMDVN) / EMDTC
      GO TO 77
164   DO 188 I =1,INTS
      IF(TOU(I) - 492.) 189, 189, 188
188   CONTINUE
      GO TO 195
189   ENSS = ENS * S
      WRITE (ITP2,2006) ENSS
2006  FORMAT(8H NS,S = F5.1,16H  FROZEN SEGMENT)
      IF(ENSS-1.01)1  ,1  ,191
191   ENS = ENS - 1.0 / S
      INTS = INTS - 1
      GO TO 64
195   TMX1 = 0.0
      TMX2 = 0.0
      DO 196 I =1,INTS
      TMX1 = TMX1 + AMVE(I) * TOU(I)
196   TMX2 = TMX2 + AMVE(I)
      TOMIX = TMX1 / TMX2
      POMIX = 6.658E-07 * EE ** (0.02531 * TOMIX)
      EMDVM = 9.06 * EMDG / (PM / POMIX - 1.)
      SHOUT = EMDVM / EMDG
      QTOT = 0.0
      QFT = 0.0
      DO 234 I = 1,INTS
      QTOT = QTOT + QTS(I)
234   QFT = QFT + QFS(I)
      QTT = QTOT - QFT
235   ENSS = ENS * S
      WRITE (ITP2,3333)
3333  FORMAT(//)
```

FIGURE D-8 (cont'd)

```
      WRITE (ITP2,2008)          TOMIX,POMIX,ENSS,QTOT,QFT,QTT,TINSA,
     1 DPTM,SHCUT,(I,TS(I),AMDG(I),AMVI(I),AMVE(I),TOU(I),ENUF(I),
     2 I=1,INTS)
2008  FORMAT(9X5HTOMIX9X5HPOMIX4X4HS,NS10X4HQTOT11X3HQFT11X3HQTT9X
     15HTINSA10X4HDPTM9X5HSHOUT/,9X5HDEG R10X4HPSIA18X4HB/HR10X4HB/HR
     210X4HB/HR9X5HDEG R11X3HPSI/ ,2F14.5,F8.1,3F14.2,F14.5,2F14.8 / ,
     323X2HTS12X3HMGI12X3HMVI12X3HMVE12X3HTOU12X3HNUE/,20X5HDEG R8X
     47HLBS/MIN8X7HLBS/MIN8X7HLBS/MIN10X5HDEG R6X9HNO OF G,S/ , (3X,I2,
     5 5X,6F15.5))
      IF(TOMIX-TOUTM)   1,601,601
1     INTS = INTS - 1
      ENS = ENS - 1.0 / S
      IF(INTS) 601,601,64
601   CONTINUE
      GO TO 600
      END
```

```
      SUBROUTINE TABLE
      DIMENSION CCC(9,3)  ,ZZZ(9,5) ,C(9) , Z(9),DERIV(22,21),DELTA(21)
      COMMON  N, J55,  IHALT, INDXS,
     1 DERIV, DELTA, C, Z, Y1, Y2, Y3, Y4 , ITP1, ITP2
C     CREATE RADIATOR INPUT TABLE
C     PROGRAM CONSTANTS - SELECTION
      DATA CCC,ZZZ/3*1.0,3*0.0,1.,2*0.0,1.125,.5,.75,0.,2*1.,.82,1.,.25,
     1.75,1.,1.5,0.,2.,2*0.,1.,.5,5*1.,0.,1.,0.,1.,1.,.5,0.,2*1.,0.,4.,2
     2*1.,1.5,3*.866,1.,0.,1.,0.,3.,2.,3*.707,1.,0.,1.,0.,4.,1.,.5,0.,1.
     3,0.,1.,4.,1.,1.,/
      READ (ITP1,1002) I,J,K,L
1002  FORMAT(4I1)
      WRITE           ( ITP2,1005)I,J,K,L
1005  FORMAT(/8H PUNT IS 2X4I1/)
      CCC(4,1) = 0.5
      DO  1   I1  = 1,9
      C(I1)  =  CCC(I1,I)
1     Z(I1)  =  ZZZ(I1,J)
      GO TO (16,15,16,16,15),J
15    Z(3) = C(4)
16    CONTINUE

      IF(K-1) 2  ,  2   ,  3
2     Y1 = 1.
      Y2 = 0.
      GO TO 4
3     Y1 =  0.
      Y2 =  1.
4     IF(L - 1)   5 ,  5 ,  6
5     Y3 = 1.
      Y4 = 0.
      RETURN
6     Y3 = 0.
      Y4 = 1.
      RETURN
      END
```

FIGURE D-8 (cont'd)

```
      SUBROUTINE CROUT
      DIMENSION A(22,21), H(21)
      COMMON  N, J55,  IHALT, INDXS, A, H
      N1=N+1
      DO 200 K=1,N
      K1=K+1
      J=K
      DO 100 I=K,N
      SUM=0.0
      IF(J-1)10,13,10
   10 IF(I-1)13,13,11
   11 IF(I-J)17,17,21
   17 ISMX=I-1
      DO 12 IS=1,ISMX
   12 SUM=SUM+A(IS,I)*A(I,IS)
   13 A(J,I)=A(J,I)-SUM
      GO TO 100
   21 JSMX=J-1
      DO 22 JS=1,JSMX
   22 SUM=SUM+A(JS,I)*A(J,JS)
   23 A(J,I)=A(J,I)-SUM
  100 CONTINUE
      I=K
      DO 200 J=K1,N1
      SUM=0.0
      IF(I-1)233,233,231
  231 ISMX=I-1
      DO 232 IS=1,ISMX
  232 SUM=SUM+A(IS,I)*A(J,IS)
  233 IF(A(I,I))350,351,350
  351 A(J,I)=0.0
      GO TO 200
  350 A(J,I)=(A(J,I)-SUM)*(1./A(I,I))
  200 CONTINUE
C     HAVE COMPLETED FINDING THE DERIVED MATRIX
      DO 300 IS=1,N
      SUM=0.0
      JS=N-IS+1
      JS1=JS+1
      DO 280 KS=JS1,N
      IF(KS-N)280,280,300
  280 SUM=SUM+A(KS,JS)*H(KS)
  300 H(JS)=A(N1,JS)-SUM
      J55=J55+1
      IF(20-J55) 302,302,303
302   IHALT = 99
      INDXS = 2
  303 RETURN
      END
```

FIGURE D-8 (cont'd)

COMPUTER FLOW CHART - ISOTHERMAL PERFORMANCE PROGRAM

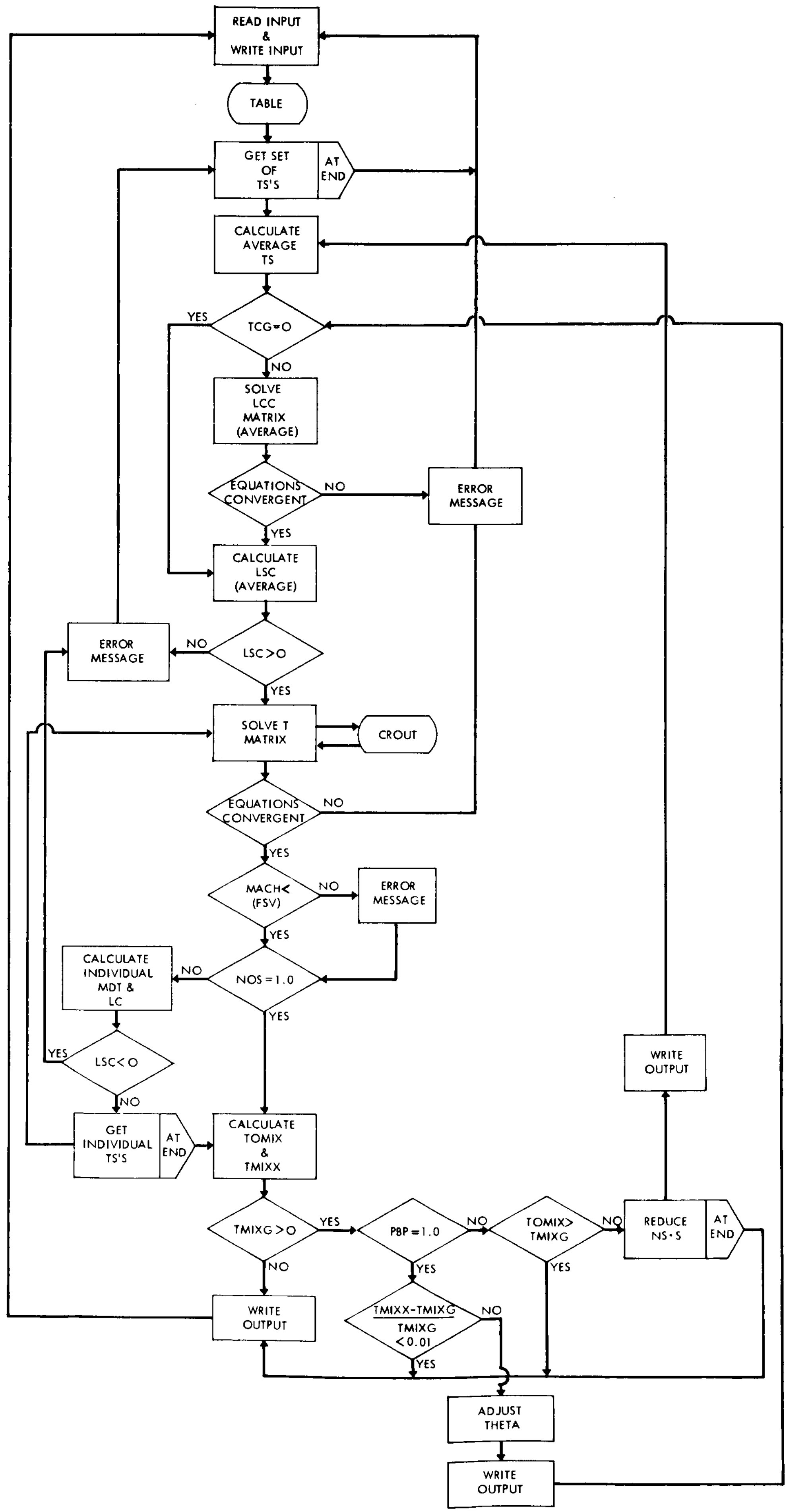

Figure D-9

SOURCE DECK PRINTOUT
ISOTHERMAL PERFORMANCE PROGRAM

```
C        TSO R/C  - ALL CONFIGS - PERFORMANCE PROGRAM
       DIMENSION D(34,33) ,B(33),C(33),ISB(7,33),T(33),RDC(33),EQCF(33,7)
      1,H(33) ,NTS(12) , TSIN(12,12), QQ(12,12,2),EMTUX(12),ELCX(12) ,
      2 TS4X(12), HCDX(12) ,TOU(12) ,WW(9),TF(9),COZ(3), TITLE(16)
       COMMON C1,C2,C3,C4,C5,C6,C7,C8,C9,Z1,Z2,Z3,Z4,Z5,Z6,Z7,Z8,Z9,
      1 Y1,Y2,Y3,Y4,ITP1,ITP2,D,H,J55,IJS
       EQUIVALENCE (T4S,TS4),(WW(1),W1),(WW(2),W2),(WW(3),W3),(WW(4),W4),
      1 (WW(5),W5),(WW(6),W12),(WW(7),W23),(WW(8),W34),(WW(9),W45),
      2 (TF(1),TF1),(TF(2),TF2),(TF(3),TF3),(TF(4),TF4),(TF(5),TF5 ) ,
      3 (TF(6),TF12),(TF(7),TF23),(TF(8),TF34), (TF(9),TF45)
       FNSP (A,B)       = (A + B) / (2.*(A + B) +CON2)
 1003  FORMAT(I2)
       ITP1 = 5
       ITP2=6
       DATA ISB/2,1,7,32,3*0,1,2,3,8,32,2*0,2,3,4,9,3*0,3,4,5,10,3*0,4,5,
      16,11,3*0,5,6,12,4*0,8,7,1,32,13,2*0,7,8,9,2,32,14,0,8,9,10,3,15,2*
      20,9,10,11,4,16,2*0,10,11,12,5,17,2*0,11,12,6,18,3*0,14,13,7,32,19,
      32*0,13,14,15,8,32,20,0,14,15,16,9,21,2*0,15,16,17,10,22,2*0,16,17,
      418,11,23,2*0,17,18,12,24,3*0,31,19,20,25,13,2*0,19,20,21,31,26,14,
      50,20,21,22,27,15,2*0,21,22,23,28,16,2*0,22,23,24,29,17,2*0,23,24,
      630,18,3*0,31,25,26,19,33,2*0,25,26,27,31,20,33,0,26,27,28,21,3*0,
      727,28,29,22,3*0,28,29,30,23,3*0,29,30,24,4*0,19,20,32,33,31,2*0,31
      8,25,26,33,3*0,1,7,13,2,8,14,32/
 2     READ (ITP1,1000) TITLE
 1000  FORMAT(16A5)
       WRITE (ITP2,1000) TITLE
       READ            ( ITP1,1003)NSETS
       DO  1    I = 1,NSETS
       READ            ( ITP1,1003)NTS(I)
       K = NTS(I)
 1     READ            ( ITP1,1004)   (TSIN(I,J),QQ(I,J,1),QQ(I,J,2)
      1   ,J =1,K)
 1004  FORMAT(3F10.4)
 1002  FORMAT(8F10.4)
       READ            ( ITP1,1002)EN, S,DIIN,DOIN,WBAR1,WBARE,TFIN,TFOUT,
      1 ELT,ELCG,HFG,EM,R,P1R,T1R,ZKC,RHOL,VISL,CL,SUFT,CV,VISV,GAMMA,
      2 ALPHS,ALPHT,ZKTH,ZKF,ET,EF,FSV,ENOS,PBP,EMDT,XIN,TCG,TCAPG,TIMTC,
      3 TMIXG
       WRITE               ( ITP2,8008)EN, S,DIIN,DOIN,WBAR1,WBARE,TFIN ,
      1 TFOUT,ELT,ELCG,HFG,EM,R,P1R, T1R,ZKC , RHOL,VISL,CL ,SUFT, CV,
      2 VISV,GAMMA,ALPHS,ALPHT,ZKTH,ZKF,ET,EF,FSV,ENOS,PBP,EMDT,XIN,TCG,
      3 TCAPG ,TIMTC ,TMIXG
 8008  FORMAT(59H PERFORMANCE ANALYSIS PROGRAM ,ISO-THERMAL DIRECT R/C
      1/SC/12H FIXED INPUT/9X1HN9X1HS6X4HDIIN6X4HDOIN5X5HWBAR15X5HWBARE6X
      24HTFIN5X5HTFOUT8X2HLT7X3HLCG7X3HHFG9X1HM/20X2(6X4HINCH)2(8X2HFT)2(
      36X4HINCH)2(8X2HFT)6X4HB/LB/12F10.4/9X1HR7X3HPIR7X3HTIR8X2HKC6X4HRH
      4OL6X4HVISL8X2HCL6X4HSUFT8X2HCV6X4HVISV5X5HGAMMA5X5HALPHS/6X4HFT/R
      56X4HPSIA5X5HDEG R30H B/HR FT F LBS/CU.FT LB/FT SEC4X6HB/LB F4X6HLB
      6S/FT3X7HB/LBS F10H LB/FT SEC/5F10.4,7F10.7/5X5HALPHT7X3HKTH8X2HKF8
```

FIGURE D-10

```
     7X2HET8X2HEF7X3HFSV7X3HNOS7X3HPBP7X3HMDT7X3HXIN7X3HTCG5X5HTCAPG/
     8 10X2(10H B/HR FT F)53X7HLBS/MIN10X2(5X5HDEG R)/12F10.4/ 5X5HTIMTC
     9 5X5HTMIXG/2(5X5HDEG R)/2F10.4//)
      CALL TABLE
      ISL1 = 0
      DV24  = DIIN /(24. *VISV)
      Y314  =  4000. *Y3 * Y1 +  10000. * Y2
      HCAPC = CL * RHOL *ZKC / VISL
      Y1427 = 1.375 * Y1 * Y4
      IF(PBP        ) 551 , 550 , 551
550   THETA = 0.
      GO TO  552
551   THETA = 0.25
552   EN6  = 6. / EN
      Y4107 = 1.07 * Y4
      ENDS  =   EN/S
      CNN27 = 40. * EMDT *CL /EN
      CNN31 = 60. *(CV * TIMTC + XIN *HFG)
      C3DN  =   C3  * DIIN
      Z5833  =  .833 * Z5
      Z55    =  .5   * Z5
      Z5167  =  .167 * Z5
      DIIN2  =   DIIN * DIIN
      DN306  =   3.06 /   DIIN2
      TCGY4=TCG+Y4-1.
      CONP = .503 * HFG * EM
      IJS=1
      D1HA = .5 * DIIN * SQRT (EN / (Z1 * S))
      RGMA = R * GAMMA
      VV12 =  12. * VISV
      CON13 = .000103 * WBAR1 /(D1HA * Z1 * S)
      CON17 = .00395 / (SUFT * DIIN * SQRT (RHOL))
      CON18 = .1275 / (DIIN * VISL)
      CON25 =   16. * VISL/(XIN * VISV * RHOL)
      DN23  =  2320. * DIIN
      C1C3P =  2. * C1 / C3
      RL432  =  432./RHOL
      RL144  =  144./RHOL
      Z2C2F  =   72 * C2  * EF
      CN41I  =                Z3 *C7 * DOIN * ET
      CN51I  =                    Z4 * C5 * DOIN * EF
      DMD = DOIN - DIIN
      DPD = DOIN + DIIN
      C1DN = C1 *DIIN
      COZ(1)=115. * Y3 * ZKC/DIIN
      COZ(3)=Y4107 *ZKC/DIIN *(VISL*CL/ZKC)**.4 / (VISL * DIIN)**.8
      COZ(2)=(CL/(DIIN * ZKC)) **.4
      DV255  =  .255 /(DIIN * VISL)
      DKY6   = 60.*Y4 * ZKC/DIIN
      Y312  = .5 * Y314
      WIN = WBAR1 *EN6 - DOIN *.5
      WOUT =WBARE *EN6 - DOIN *.5
      CLEN  = CL *60. * ENDS
      ENS13  =  13.34 *ENDS * ZKF
      CN41   = -1.495E-10  * CN41I
      CN42   = -.715E-10   * CN41I
      CN51   =  -.238E-10  * CN51I
      CN52   =  -.357E-10  * CN51I
```

FIGURE D-10 (cont'd)

```
      DDD =  C2 * ZKTH * DMD/ DPD
      D2D2  =                DMD * DPD * ZKTH
      DDK  = DMD/ ZKTH
      C1D4 = 1.394 * C1DN
      CN61 = .348 * C3DN
      WIMWO = WIN - WOUT
      DDD17 =  1.7 * DDD
      DDD85 =  .85 * DDD
      D2D21 = .0109 * C1 *D2D2
      D2D23 = .002722 * C3*D2D2
      CON6 = WIN + WOUT
      IF(C5-1.)  31 , 35  , 39
 31   CON1 = 2. * DOIN / CON6
      F3SP = SQRT (.05 * CON1 +.0025) / (CON1 +.1) +  SQRT (3.803+ 1.95*
     1  CON1) / (CON1 + 3.9)
      F4SP = SQRT (.2  * CON1 +.04  ) / (CON1 +.4) +  SQRT (3.24 + 1.8 *
     1  CON1) / (CON1 + 3.6)
      F5SP = SQRT (.45 * CON1 +.2025) / (CON1 +.9) +  SQRT (2.403+ 1.55*
     1  CON1) / (CON1 + 3.1)
      F6SP = SQRT (.8  * CON1 +.64  ) / (CON1 +1.6)+  SQRT (1.44 + 1.2 *
     1  CON1) / (CON1 + 2.4)
      CON2 = CON6/ DOIN
      CON3 = 1. / (1. + 2.*CON2)
      F1SP = .6366 *(1. + CON2 * (1.- SQRT (1.+DOIN/CON6)) + .5  *
     1  ATAN ( SQRT (1. - CON3 * CON3) / CON3 )   )
      GO TO 40
 35   IF(73) 351,39,351
 351  CON1 = DOIN / WIN
      CON2 = CON1 * CON1
      F3SP = FNSP (.05*CON1,.0025)  + FNSP (1.95 *CON1,3.803)
      F4SP = FNSP (.2 *CON1,.04  )  + FNSP (1.8  *CON1,3.24 )
      F5SP = FNSP (.45*CON1,.2025)  + FNSP (1.55 *CON1,2.403)
      F6SP = FNSP (.8 *CON1,.64  )  + FNSP (1.2  *CON1,1.44 )
      F1SP = .3183 *(ATAN  (1. + 4./CON1) + .2146)
      GO TO 40
 39   F3SP  =1.
      F4SP  =1.
      F5SP  =1.
      F6SP  =1.
      F1SP = 1.
 40   DO 998   III = 1, NSETS
      ENS = 1.
      NNS  = S +.0001
 33   ENSS  =  S *  ENS
      ENNS   =   EN * ENS
      JJJ=NNS
      SUM = 0.
      DO  653  I = 1,JJJ
      TS4X(I) = TSIN(III,I)*TSIN(III,I)*TSIN(III,I)*TSIN(III,I)
      IF(TSIN(III,I))651,653,653
 651  TS4X(I) = 5.83E+8 * ALPHS/ALPHT * QQ(III,I,1) + QQ(III,I,2)
 653  SUM = SUM + TS4X(I)
      T4S     =   SUM / ENSS
      TSAVG  =  T4S
      TS    = TSAVG**.25
      WRITE              ( ITP2,9912)III,TS
 9912 FORMAT(/6H GROUPI3,20H VALUE OF TS AVG. IS F8.1,6H DEG R/)
      TCAP = TCAPG + TCG
```

FIGURE D-10 (cont'd)

```
      PCAP = P1R* EXP ((TCAP/T1R -1.) *        CONP    /TCAP)
      ROVAP=     EM09    * PCAP /TCAP
3     EMTU = EMDT *(1. - THETA) /ENNS
      JCNT = 0
      ISW1 = 1
      IREP = 0
705   VINAP = DN306 *EMTU / ROVAP
      REAP = DV24 * VINAP * ROVAP
      IF(REAP - 2000.)  71  , 71   , 72
71    FRAP  = 64. / REAP
      GO TO  8
72    IF(REAP - 4000.)  73  ,  74  , 74
73    FRAP =  .00277 * REAP ** .322
      GO TO 8
74    FRAP =  .316 / REAP **.25
8     GO TO (800,491) ,ISW1
800   HCAP = Y1427 * VINAP *SQRT (HCAPC *ROVAP*FRAP) + Y314
      IF(TCG)     21,  22 ,  21
21    CON3 =  2. * ELT
      CNL1 =  WIMWO       / CON3
      CNL2 = (TFIN - TFOUT) / CON3
      CNL3 =  TFIN * WIN
      CNL6 =  C1D4 / (48./HCAP + DDK)
      CNL7 = .5 * CNL6 / C1C3P
C     7 SIMULTANEOUS  T -LCC -T**4   EQUATIONS
C     6 TEMPERATURE UNKNOWNS ,  1 LCC
C     CONSTRUCT DERIVITIVE MATRIX   D(8,7)
      J55 =0
      DO 801 I = 1,6
801   T(I) = 1050-16 *I
      T(7)=5.
802   DO 803 I = 1,6
      C(I) = T(I) * T(I) * T(I)
      DO 803 J = 1,7
803   D(I,J) = 0.
      T12 =  T(1) - T(2)
      T23 =  T(2) - T(3)
      T34 =  T(3) - T(4)
      T45 =  T(4) - T(5)
      T56 =  T(5) - T(6)
      CNL4 = T(7) *CNL1
      CNL5 = WIN - CNL4
      CNL11 =  CNL7 *(TCG - T(2))
      ELDIR = (CNL3 - CNL2 *T(7)* (WIN+CNL5)) / (CNL5 * CNL5) * 7KF
      ELRDR = (WIN - 2. * CNL4) * 72C2F
      ELTRM =(T(7) *(TFIN -T(7)* CNL2) / CNL5) * ZKF
      CNL8 = T(7) * (WIN - T(7)* CNL1) * 72C2F
      CON1 = CNL8 / ELRDR
      D(7,2) =  - T23        * 6.67 * ELDIR
      D(7,4) = 2.22 * ELDIR * T34
      D(7,3) = - D(7,4) - D(7,2)
      D(7,5) =1.334 * ELDIR *  T45
      D(7,4) =  D(7,4) - D(7,5)
      D(7,6) =  0.952 * ELDIR * T56
      D(7,5) =  D(7,5) -  D(7,6)
      D(5,6) =  .952 * ELTRM
      D(4,5) = 1.334 * ELTRM
      D(6,5) = D(5,6)
```

FIGURE D-10 (cont'd)

```
      D(3,4) =  2.22 * ELTRM
      D(5,4) = D(4,5)
      D(2,3) =  6.67 * ELTRM
      D(4,3) =  D(3,4)
      D(3,2) =  D(2,3)
      D(2,1) = DDD17 * T(7)
      D(7,2) = D(7,2) +CNL11+.5*DDD17*T12
      D(1,2) = .5 * D(2,1)
      CNL9  = -3.8E-11 * CNL8 * (C6+ F6SP)
      D(6,6) = 4. * C(6) * CNL9 - D(5,6)
      CNL9  =  (T(6) * C(6) - T4S) * CNL9
      D(7,6)  =  D(7,6) +          CNL9 / CON1
      D(8,6)  =  -CNL9          - T56 * D(5,6)
      CNL9  = -2.85E-11 * CNL8 * (C6 + F5SP)
      D(5,5) = 4.   * C(5) * CNL9  - D(4,5) -  D(6,5)
      CNL9  =  (T(5) * C(5)  - T4S)   * CNL9
      D(7,5) =  D(7,5)  +          CNL9/ CON1
      D(8,5) =  - CNL9          - T45 * D(4,5)     +T56 *  D(6,5)
      CNL9 =  -1.90E-11 * CNL8 * (C6 + F4SP)
      D(4,4) =  4. * C(4) * CNL9  - D(5,4) -  D(3,4)
      CNL9   =  (T(4) * C(4) - T4S) * CNL9
      D(7,4) =  D(7,4) +         CNL9 / CON1
      D(8,4) =   -CNL9   - T34 * D(3,4) + T45 * D(5,4)
      CNL9   = -.950E-11 * CNL8 * ( C6 + F3SP)
      D(3,3) =  4. * C(3) * CNL9  - D(4,3)  -  D(2,3)
      CNL9   = (T(3)  *  C(3) - T4S) * CNL9
      D(7,3) =   D(7,3) +  CNL9 / CON1
      D(8,3) =   - CNL9   - T23 * D(2,3) + T34 * D(4,3)
      CNL9   = -.238E-10 * CN51I *  T(7)
      D(2,2) =  4. * C(2) * CNL9 - D(3,2) - D(1,2) - T(7) * CNL7
      CNL9  =  (T(2) * C(2) - T4S) * CNL9
      D(7,2) =  D(7,2) +  CNL9 / T(7)
      D(8,2) =  -CNL9 + T23 *D(3,2) - T12 * D(1,2) - CNL11 * T(7)
      CNL9=-1.495E-10 * F1SP*CN41I * T(7)
      D(1,1) =  4. * C(1) * CNL9   - D(2,1) -  CNL6 * T(7)
      CNL9  =   (T(1) * C(1) - T4S) * CNL9
      CON2  =   CNL6 * (TCG - T(1))
      D(7,1) =  CON2  - DDD17 * T12   + CNL9 /  T(7)
      D(8,1) =  - CNL9 + T12 * D(2,1) - CON2  * T(7)
      D(1,7) =  CNL6 * T(7)
      D(2,7) =  CNL7 * T(7) * 2.
      D(7,7) =  - CON2   - 2. * CNL11
      D(8,7) =  -T(7) * D(7,7) - CNN31 *.3333333*EMTU
      CALL CROUT(7)
      GO TO (805,804) ,IJS
804   WRITE            ( ITP2,8041        )
8041  FORMAT(/37H20 CYCLES--NOT CONVERGED-- LCC MATRIX/)
      GO TO 2
805   DO 806 K = 1,7
806   T(K) = T(K) + H(K)
      IF(ABS (H(7)) - .0005) 807, 802 , 802
807   DO 8061 K=1,6
      IF(ABS (H(K))- 1.) 8061,802,802
8061  CONTINUE
      ELC = T(7)
      GO TO 2201
22    ELC = ELCG
2201  ELSC = ELT- ELC
```

FIGURE D-10 (cont'd)

```
      IF(ELSC)  221 ,   23  , 23
221   WRITE              ( ITP2,1100) ELSC
1100  FORMAT(/19HSTOP,NEGATIVE LSC  ,F10.5)
      GO TO 9981
23    CON1 = EMTU * DV255
      ENEL  = ENDS *20. * ELSC * ZKF
      EML1 =.00545 * DIIN2 *RHOL/S *(EN * ELSC + WBARE)
      CON2= EMTU**.4
      HSC=COZ(1)*CON2*COZ(2)
      IF(CON1- 2300.) 2301 , 2301 , 2302
2301  HSC = HSC + DKY6
      GO TO 2303
2302  HSC = HSC + CON2*CON2*COZ(3)
2303  EL1 = .167 * ELC
      EL2 = .5    *ELC
      EL3 = .833 *ELC
      EL4 =  ELC + .25 * ELSC
      EL5 =  ELC + .75 * ELSC
      ELT =  ELC +  ELSC
      EL23  = 2.*ELC + 3.* ELSC
      EM09 = .0932 * EM
      CON1 = ELT - EL1
      CON2 = ELT - EL2
      CON3 = ELT - EL3
      CON21= ELT - EL4
      CON22= ELT - EL5
      W1 = ( WIN *  CON1       + WOUT * EL1 ) / ELT
      W2 = ( WIN *  CON2       + WOUT * EL2 ) / ELT
      W3 = ( WIN *  CON3       + WOUT * EL3 ) / ELT
      W4 = ( WIN *  CON21      + WOUT * EL4 ) / ELT
      W5 = ( WIN *  CON22      + WOUT * EL5 ) / ELT
      W12 = .5 *(W1 + W2)
      W23 = .5 *(W2 + W3)
      W45 = .5 *(W4 + W5)
      ELLC= (ELC / ELSC)* .66666667
      W34 =  ( W3 + ELLC * W4) / ( 1. + ELLC)
      TF1 = ( TFIN * CON1  + TFOUT * EL1 )    / ELT
      TF2 = ( TFIN * CON2  + TFOUT * EL2 )    / ELT
      TF3 = ( TFIN * CON3  + TFOUT * EL3 )    / ELT
      TF4 = ( TFIN * CON21 + TFOUT * EL4 )    / ELT
      TF5 = ( TFIN * CON22 + TFOUT * EL5 )    / ELT
      TF12 = .5 *(TF1 + TF2)
      TF23 = .5 *(TF2 + TF3)
      TF45 = .5 *(TF4 + TF5)
      TF34 = (TF3 + ELLC *TF4) / (1. + ELLC)
      WIF = WIN - WIMWO * ELC / ELT
      WNPWF = WIN + WIF
      CON1 = WIN / WNPWF
      CON6 = (WIN - WIF) / WNPWF
      ZKK1 = Z5833 + Z6 * (1. - 1.666 * CON1 + .695 * CON6)
      ZKK2 = Z55   + Z6 * (1. -         CON1 + .25  * CON6)
      ZKK3 = Z5167 + Z6 * (1. - .333    * CON1 + .0279* CON6)
491   HCOND = Y1427 * ZKK2 * VINAP * SQRT (HCAPC *ROVAP*FRAP) + Y312
C     CALC. RDC , B  , EQCF
      CON1= CN41 * ELC  *  F1SP
      CON2= CN51 *ELC
      CON3= Z2C2F* ELC
      CNN7 = ELSC * ZKF
```

FIGURE D-10 (cont'd)

```
      CNN8 = ZKF/  ELSC
      CNN9 = D2D2 *C3
      CNN10 = CNN9 *,00182 /ELSC
      CNN11 = 4, * ELC / EL23
      DDDLS =1.272 * ELSC * DDD
      CNN13  =   ,0083333   * ZKF * TF34 * W34 /EL23
      CNN12  =  CNN10 * C1C3P
      DO 3010    I = 1,13,6
      J = 1 +   I/6
      CON6=  CON3 * WW(J)
      RDC(I) = CON1
      RDC(I+1) = CON2
      RDC(I+2) = -,95E-11 * CON6* (C6 + F3SP)
      RDC(I+3) = -1,9E-11 * CON6* (C6 + F4SP)
      RDC(I+4) = -2,85E-11* CON6* (C6 + F5SP)
 3010 RDC(I+5) = -3,80E-11* CON6* (C6 + F6SP)
      CON1= CN42 *ELSC
      CON2=  CN52 *ELSC
      CON3=  Z2C2F * ELSC
      DO  3011    I = 19,25,6
      J = 1  +  I/6
      CON6=CON3*WW(J)
      RDC(I) = CON1
      RDC(I+1) = CON2
      RDC(I+2) = -,1428E-10 * CON6* (C6 + F3SP)
      RDC(I+3) = -,285E-10  * CON6* (C6 + F4SP)
      RDC(I+4) = -,428E-10  * CON6* (C6 + F5SP)
 3011 RDC(I+5) = -,570E-10  * CON6* (C6 + F6SP)
      DO 3020 I = 1,30
 3020 B(I) = TS4 * RDC(I)
      DO 3021 I = 31,33
      RDC(I) =  0,
 3021 B(I) = 0,
      CON6 = D2D21/ELC
      HC9 =        ELC      / (24,/HCOND + DDK)
      HS1 =        ELSC     / (24,/HSC    + DDK)
      CON23 =    C1DN   * HS1
      CON24 =    C3DN   * HS1
      CON21=C1D4 * HC9
      CON22=CN61 *HC9
      CON1= ELC * ZKF
      CON2= ZKF / ELC
      CN13 = ELC * DDD85
      CN14 = D2D23 /ELC
      DO 3050 I = 1,5
      J = 6 * I
      K = 6 + I/3
      IF(I-4) 3030, 3035 , 3035
 3030 CN11 = TF(I)/WW(I)   * CON1
      CN12 = TF(K) *WW(K) * CON2
      EQCF(J,1) = ,952   * CN11
      EQCF(J,3) = ,00834 *CN12
      EQCF(J-1,1) = 1.334   * CN11
      EQCF(J-1,3) = EQCF(J,1)
      EQCF(J-1,4) =,00624   * CN12
      EQCF(J-2,1) = 2,22 * CN11
      EQCF(J-2,3) = EQCF(J-1,1)
      EQCF(J-2,4) = ,00417 * CN12
```

FIGURE D-10 (cont'd)

```
      EQCF(J-3,1) = 6.67 * CN11
      EQCF(J-3,3) = EQCF(J-2,1)
      EQCF(J-3,4) = .002085 * CN12
      EQCF(J-4,1) = CN13
      EQCF(J-4,3) = EQCF(J-3,1)
      EQCF(J-4,4) = CN14
      EQCF(J-4,5) = CON22
      EQCF(J-5,4) = CON21
      EQCF(J-5,1) = 2.* CN13
      EQCF(J-5,3) = CON6
      IF(I-2) 3050 , 3031  , 3033
 3031 DO  3032  L = 9,11
 3032 EQCF(L,5) = EQCF(L,4)
      EQCF(7,5) = EQCF(7,3)
      EQCF(8,6) = EQCF(8,4)
      EQCF(12,4)= EQCF(12,3)
      GO TO 3050
 3033 EQCF(13,5) = CNN11 * EQCF(13,3)
      EQCF(14,6) = CNN11 * EQCF(14,4)
      EQCF(15,5) = CNN13
      EQCF(16,5) = 2. * CNN13
      EQCF(17,5) = 3. * CNN13
      EQCF(18,4) = 4. * CNN13
      GO TO 3050
 3035 CN11 = TF(I)/WW(I)  *CNN7
      CN12 = TF(K)*WW(K)  *CNN8
      EQCF(J,1) = 1.428  * CN11
      EQCF(J-1,3) = EQCF(J,1)
      EQCF(J-1,1) = EQCF(J-1,3) / .714
      EQCF(J-1,4) = .00416 * CN12
      EQCF(J-2,3) = EQCF(J-1,1)
      EQCF(J-2,1) = EQCF(J-2,3) * 1.665
      EQCF(J-3,3) = EQCF(J-2,1)
      EQCF(J-3,1) = 3.003  * EQCF(J-3,3)
      EQCF(J-4,3) = EQCF(J-3,1)
      EQCF(J-4,5) = CNN10
      EQCF(J-4,1) = DDDLS
      EQCF(J,3) = EQCF(J-1,4) * 1.336
      EQCF(J-2,4) = EQCF(J-1,4) * .6667
      EQCF(J-3,4) = EQCF(J-1,4) * 0.3333
      EQCF(J-4,4) = .523 * CON24
      EQCF(J-5,3) = EQCF(J-4,1)
      EQCF(J-5,4) = CNN12
      EQCF(J-5,1) = 1.046 * CON23
      IF(I-5) 3050, 3037,  3050
 3037 EQCF(19,5) = .5 * EQCF(13,5)
      EQCF(20,6) =  EQCF(14,6)
      DO 3038  L = 21,23
 3038 EQCF(L,5) = EQCF(L-6,5)
      EQCF(24,4) = EQCF(18,4)
 3050 CONTINUE
      EQCF(26,4) = .33333 * EQCF(20,4)
      EQCF(26,6) = 2. * EQCF(26,4)
      EQCF(25,1) = .33333 * EQCF(19,1)
      EQCF(25,5) = 2. * EQCF(25,1)
      DO 3051 L= 1,30
      EQCF(L,2)=-EQCF(L,1)
      DO 3051 I= 3,6
```

FIGURE D-10 (cont'd)

```
 3051 EQCF(L,2)= EQCF(L,2) - EQCF(L,I)
      EQCF(31,1) = EQCF(19,1) * 2.0
      EQCF(31,2) = EQCF(31,1) /C1C3P
      CON2  = CNN27 / ENS
      EQCF(31,3) = 1.5   * CON2
      EQCF(31,4) =-.5    * CON2
      EQCF(31,5) = -CON2  - EQCF(31,1) - EQCF(31,2)
      EQCF(32,2) = EQCF(31,1)
      EQCF(32,3) = EQCF(31,2)
      CON1  = EQCF(32,2) +EQCF(32,3)
      EQCF(32,1) = -.33333333 * CON1+CON2
      EQCF(32,4) = -.66666667 * CON1-CON2
      B(33) = EMTU * CNN31
      DO 3052  L = 1,3
      EQCF(33,L) = - EQCF(13,4)
 3052 EQCF(33,L+3) = -EQCF(14,5) * 2.
      EQCF(33,7)  = -3. * (EQCF(33,1) + EQCF(33,4))
C       33  SIMULTANEOUS  4TH DEGREE TEMPERATURE UNKNOWN  EQUATIONS
C       CONSTRUCT DERIVITIVE MATRIX  D(34,33)
      IF(IREP)3990,3990,3992
 3990 IF(TCG)3991,3993,3991
 3993 IF(JCNT)3991,3991,3992
 3991 DO 399  J = 1,33
 399  T(J) = 1000.
 3992 J55  =  0
 400  DO 401  J = 1,33
      C(J) = T(J) * T(J) * T(J)
      DO 401  I = 1,33
 401  D(I,J)  =  0.
      DO 410  K = 1,33
      CON1=4. * RDC(K) * C(K)
      D(34,K)  = B(K) - .25 *CON1* T(K)
      DO 407  L1 =  1,7
      J =  ISB(L1,K)
      IF(J) 410 ,410,402
 402  IF(K - J)  406, 405 , 406
 405  D(J,K) =  EQCF(K,L1) + CON1
      GO TO 407
 406  D(J,K) =  EQCF (K,L1)
 407  D(34,K) =  D(34,K) - EQCF(K,L1)* T(J)
 410  CONTINUE
      ISL1 = 0
      CALL CROUT(33)
      GO TO (413,412),IJS
 412  WRITE            ( ITP2,4121       )
 4121 FORMAT(/37H20 CYCLES--NOT CONVERGED-- T   MATRIX/)
      GO TO 2
 413  DO 415 K = 1,33
      T(K) = T(K) + H(K)
      IF(ABS (H(K)) -1.)  415,414,414
 414  ISL1 = 1
 415  CONTINUE
      IF(ISL1) 44,44,400
 44   TC   = T(32)
      TOUT = T(33)
      TC4=TC*TC
      TC4=TC4*TC4
      IF(IREP)  508, 508  ,519
```

FIGURE D-10 (cont'd)

```
 508    TCAVG =  T(32)
        IF(TCGY4) 52,51,52
 51     IF(ABS (1. - TCAPG/TC) - .02)   52 , 52   ,511
 511    JCNT= JCNT +1
        IF( JCNT -3) 512 ,   52 , 52
 512    TCAP = TC + TCG
        PCAP = P1R *EXP ((TCAP/T1R -1.) * CONP /TCAP)
        ROVAP = EM09 * PCAP / TCAP
        ISW1  = 2
        GO TO 705
 519    TOU(IREP) = TOUT
 52     PC = P1R *EXP ((TC/T1R -1.)   * CONP /TC )
        JCNT =  0
        RHOV = EM09 * PC /TC
        VIN =  DN306 * EMTU / RHOV
        SOVV =  5.67 * SQRT (RGMA * TC)
        AMACH = VIN/SOVV
        IF(FSV - AMACH)   54  , 55    , 55
 54     WRITE            ( ITP2,541)AMACH
 541    FORMAT(/5H MACHF10.2,2X20HIS TOO HIGH--WARNING )
 55     CON1  = RHOV * VIN
        CON3  =  CON1  * VIN
        CON2  = CON1  / VV12
        CON21 = CON2  * DIIN
        RE1HA = CON2  * D1HA
        DP1H  = CON13 * CON3         / (RE1HA)**.25
        REV1 =  ZKK1  * CON21
        REV2 =  ZKK2  * CON21
        REV3 =  ZKK3  * CON21
        IF(REV1 - 2000.)  61 , 61 , 611
 61     FR1   =  64./ REV1
        GO TO 62
 611    IF(REV1- 4000.) 612  ,  613 ,   613
 612    FR1  =  .00277 * REV1 **.322
        GO TO 62
 613    FR1   = .316 / REV1 **.25
 62     IF(REV2 - 2000.) 621 ,621 ,622
 621    FR2 =  64./ REV2
        GO TO 63
 622    IF(REV2 - 4000.) 623 , 624 ,624
 623    FR2  =  .00277 * REV2 **.322
        GO TO 63
 624    FR2 = .316 /REV2 **.25
 63     IF(REV3 - 2000.) 631,631,632
 631    FR3 = 64. / REV3
        GO TO 64
 632    IF(REV3 - 4000.) 633 , 634  , 634
 633    FR3  = .00277 * REV3  **.322
        GO TO 64
 634    FR3  = .316/REV3**   .25
 64     CON21 = 1.- ZKK1 * XIN
        CON22 = 1.- ZKK2 * XIN
        CON23 = 1.- ZKK3 * XIN
        CON24 = EMTU * VIN   * SQRT (RHOV) * CON17
        WEF1  = ZKK1  * CON24 *CON21
        WEF2  = ZKK2  * CON24 *CON22
        WEF3  = ZKK3  * CON24 *CON23
        CON1= CON18 * EMTU
```

FIGURE D-10 (cont'd)

```
      RF1 = CON1* CON21
      RF2 = CON1* CON22
      RF3 = CON1* CON23
      CON26 = CON25 * RHOV
      FK1 = FR1 * ZKK1
      FK2 = FR2 * ZKK2
      FK3 = FR3 * ZKK3
      IF(WEF1- 3.)  70 ,   70, 702
70    IF(RF1 - 200.) 701,  701, 702
701   DR1 = SQRT (CON21 * CON26/(FK1 * REV1))
      IF(REV1 - 2000.) 7011 , 7011 , 7012
7011  PH11 = (1.0 + DR1) ** 4.0
      GO TO 703
7012  PH11 = (.5 + SQRT (.25 + DR1)) **4.75
      GO TO 703
702   PH11 = (ZKK1 *XIN)**(-.75)
703   IF(WEF2 - 3.) 710,710,712
710   IF(RF2 - 200.)  711,  711, 712
711   DR2 = SQRT (CON22 * CON26/(FK2 *REV2))
      IF(REV2 - 2000.) 7111, 7112 ,  7112
7111  PH12  =  (1. + DR2) **( 4.)
      GO TO 713
7112  PH12  = (.5 + SQRT (.25 + DR2))** 4.75
      GO TO 713
712   PH12 = (ZKK2 *XIN)**(-.75)
713   IF(WEF3 -3.)  720,720,722
720   IF(RF3 - 200.) 721 ,721,722
721   DR3 = SQRT (CON23 * CON26 /(FK3 * REV3))
      IF(REV3 - 2000.) 7211,7211, 7212
7211  PH13 =  ( 1. +DR3)  **( 4.)
      GO TO 76
7212  PH13 =  ( .5 + SQRT (.25+ DR3))**4.75
      GO TO 76
722   PH13 = (ZKK3 * XIN) **(-.75)
76    DPLC = ELC * CON3   *(PH11 *ZKK1 *FK1 + PH12 *ZKK2 *FK2   +
     1 PH13 *ZKK3 * FK3)  / DN23
      CON6=CON3/9260.
      DPTOT = DPLC + DP1H  - CON6
      PPWR=EMDT*DPTOT/(236.*RHOL)
      FNUE  =-RL432 *(1.435E-4 * CON3  - DPLC) / ELC
      FNPG  =-RL144 *(CON6  - DPLC) / ELSC
      QTOTC  =  ENDS * B(33)
      QFTC = ENS13 * ELC *( (T(2)-T(3))*TF1/W1 + (T(8)- T(9))*TF2 /W2 +
     1   (T(14) - T(15)) * TF3/W3 )
      QTTC = QTOTC - QFTC
      QTOTS = CLEN *EMTU * (T(32) - T(33))
      QFTS  = ENEL *((T(20)- T(21)) *TF4/W4 + (T(26)- T(27))*TF5/W5 )
      QTTS  = QTOTS - QFTS
      QTOT  = QTOTC + QTOTS
87    WRITE              ( ITP2,870)IREP
870   FORMAT(/8H SET NO,I3)
      EMDS = EMTU * ENDS
      TS =  TS4 **.25
      WRITE              ( ITP2,871)
     1                          TC,PC,ELC,ELSC,TOUT,DPTOT,FNUF ,FNPG ,
     2 QTOTC,QTOTS ,QTOT ,EML1,EMDS,       VIN , AMACH , TS
871   FORMAT(13X2HTC13X2HPC13X2HLC12X3HLSC11X4HTOUT10X5HDPTOT12X3HNUE12X
     13HNPG/10X5HDEG R11X4HPSIA13X2HFT13X2HFT10X5HDEG R12X3HPSI6X9HNO OF
```

FIGURE D-10 (cont'd)

```
     2 G,S6X9HNO OF G,S/
     3       8F15.5/10X5HQTOTC10X5HQTOTS11X4HQTOT12X3HML112X3HMDS
     412X3HVIN         11X4HMACH13X2HTS/3(11X4HB/HR)12X3HLBS8X7HLBS/MIN9X
     5 6HFT/SEC25X5HDEG R/3F15.2,5F15.5/)
 872  IF(IREP)  88,88,95
 88   IF(ENOS-1.) 89,97,89
 89   IF(.33333333 *(REV1 + REV2 + REV3)- 2000.) 891  ,   891  ,892
 891  EX  = 1.0
      GO TO 90
 892  EX  = 1.75
 90   CON1=TC4-TS4
      CON2 = EMDT/(EN*EMTU)   *(1.-THETA)
      EXP1=1./(EX +1.)
      IF(TCG)906,901,906
 901  TCM4=TC4
      SUMN=0.
      SUMD=0.
 902  DO 903 I=1,NNS
      CON6=1.-TS4X(I)/TCM4
      CON24=CON6**EXP1
      SUMD=SUMD+CON24
 903  SUMN=SUMN+CON24/CON6
      TCM41=CON2*CON1*SUMN/(SUMD*ENS)
      IF(ABS (TCM41-TCM4)-1.E+8)905,905,904
 904  TCM4=TCM41
      GO TO 902
 905  TCM4=TCM41
      TCM=TCM4**.25
      GO TO 907
 906  TCM4=TC4
 907  SUMD=0.
      DO 908 I=1,NNS
 908  SUMD=SUMD+(TCM4-TS4X(I))**EXP1
      DPTM=DPTOT*CON1*(CON2*S/SUMD)**(EX +1.)
      PPWR=EMDT*DPTM /(236.*RHOL)
      DO 909 I=1,NNS
      SUMN=CON1/(TCM4-TS4X(I))
      EMTUX(I)=EMTU*(DPTM/SUMN/DPTOT)**EXP1
      ELCX(I)=SUMN*EMTUX(I)*ELC/EMTU
      IF(ELCX(I)-ELT) 909,910,910
 909  CONTINUE
      GO TO 911
 910  WRITE            ( ITP2,9971       )
 9971 FORMAT(/20H UNSTABLE---LC GT LT/)
      GO TO 998
 911  IF(TCG)922,921,922
 921  RHOVM = EM09 *P1R/TCM *EXP ((TCM/T1R-1.) * CONP/TCM)
      GO TO  93
 922  RHOVM = RHOV
      TCM=0.
 93   DO931  I = 1,NNS
 931  HCDX(I) = Y312 + ZKK2 * DN306 *EMTUX(I)/RHOVM * SQRT ( HCAPC   *
     1 RHOVM * FR2) *Y1427
 95   IREP = IREP + 1
      IF(IREP - NNS) 951, 951,96
 951  ELC = ELCX(IREP)
      EMTU = EMTUX(IREP)
      TS4 =  TS4X(IREP)
```

FIGURE D-10 (cont'd)

```
      HCOND = HCDX(IREP)
      GO TO 2201
96    TOMIX =  0.
      DO 961  I = 1,NNS
961   TOMIX = TOMIX  + TOU(I) * EMTUX(I)
      TOMIX = TOMIX / (ENSS * EMTU)
      GO TO  98
97    TOMIX = TOUT
      TCM=0.
      DPTM=0.
98    IF(TMIXG)99,998,99
99    IF(PBP)994,991,994
991   TMIXX=0.
      IF(TOMIX-TMIXG)995,998,998
995   NNS=NNS-1
      ENS=ENS-1./S
      WRITE            (ITP2,9983)ENSS,THETA,TOMIX,TMIXX,DPTM,TCM,PPWR
      IF(NNS)9981,9981,33
994   TMIXX=(1.-THETA)*TOMIX+THETA*(TC+XIN*HFG/CL+(TIMTC  )*CV/CL)
      IF(ABS (TMIXX-TMIXG)/TMIXG-.01)998,996,996
996   THETA=THETA+(TMIXG-TMIXX)/(TIMTC*CV/CL-TMIXG+HFG*XIN/CL)
      WRITE            (ITP2,9983)ENSS,THETA,TOMIX,TMIXX,DPTM,TCM,PPWR
      GO TO 3
998   WRITE            (ITP2,9983)ENSS,THETA,TOMIX,TMIXX,DPTM,TCM,PPWR
9983  FORMAT(/11X4HNS,S10X5HTHETA10X5HTOMIX10X5HTMIXX11X4HDPTM12X3HTCM
     2 11X4HPPWR /30X2(10X5HDEG R)12X3HPSI10X5HDEG R13X2HHP/7F15.5)
9981  CONTINUE
      GO TO 2
      END

      SUBROUTINE TABLE
      DIMENSION CCC(9,3)  ,ZZZ(9,5) ,C(9) , Z(9 )
      COMMON C,Z,Y1,Y2,Y3, Y4 ,ITP1,ITP2
C     CREATE RADIATOR INPUT TABLE
C     PROGRAM CONSTANTS - SELECTION
      DATA CCC,ZZZ/3*1,0,3*0,0,1.,2*0.0,1.125,.5,.75,0.,2*1.,.82,1.,.25,
     1.75,1.,1.5,0.,2.,2*0.,1.,.5,5*1.,0.,1.,0.,1.,1.,.5,0.,2*1.,0.,4.,2
     2*1.,1.5,3*.866,1.,0.,1.,0.,3.,2.,3*.707,1.,0.,1.,0.,4.,1.,.5,0.,1.
     3,0.,1.,4.,1.,1./
      CCC(4,1) = 0.5
      READ (ITP1,1002) I,J,K,L
1002  FORMAT(4I1)
      WRITE            ( ITP2,1005)I,J,K,L
1005  FORMAT(78H PUNT IS 2X4I1/)
      DO  1    I1  = 1,9
      C(I1)  =  CCC(I1,I)
1     Z(I1)  =  ZZZ(I1,J)
      GO TO (16,15,16,16,15),J
15    Z(3) = C(4)
16    CONTINUE
      IF(K-1) 2  ,  2   ,  3
2     Y1 = 1.
```

FIGURE D-10 (cont'd)

```
      Y2 = 0.
      GO TO 4
3     Y1 =  0.
      Y2 =  1.
4     IF(L - 1)    5 ,  5 ,  6
5     Y3 = 1.
      Y4 = 0.
      RETURN
6     Y3 = 0.
      Y4 = 1.
      RETURN
      END
      SUBROUTINE CROUT(N)
      DIMENSION H(33),A(34,33),SPACE(24)
      COMMON SPACE,A,H,J55,IJS
      N1=N+1
      DO 200 K=1,N
      K1=K+1
      J=K
      DO 100 I=K,N
      SUM=0.0
      IF(J-1)10,13,10
   10 IF(I-1)13,13,11
   11 IF(I-J)17,17,21
   17 ISMX=I-1
      DO 12 IS=1,ISMX
   12 SUM=SUM+A(IS,I)*A(I,IS)
   13 A(J,I)=A(J,I)-SUM
      GO TO 100
   21 JSMX=J-1
      DO 22 JS=1,JSMX
   22 SUM=SUM+A(JS,I)*A(J,JS)
   23 A(J,I)=A(J,I)-SUM
  100 CONTINUE
      I=K
      DO 200 J=K1,N1
      SUM=0.0
      IF(I-1)233,233,231
  231 ISMX=I-1
      DO 232 IS=1,ISMX
  232 SUM=SUM+A(IS,I)*A(J,IS)
  233 IF(A(I,I))350,351,350
```

FIGURE D-10 (cont'd)

```
  351 A(J,I)=0.0
      GO TO 200
  350 A(J,I)=(A(J,I)-SUM)*(1./A(I,I))
  200 CONTINUE
C     HAVE COMPLETED FINDING THE DERIVED MATRIX
      DO 300 IS=1,N
      SUM=0.0
      JS=N-IS+1
      JS1=JS+1
      DO 280 KS=JS1,N
      IF(KS-N)280,280,300
  280 SUM=SUM+A(KS,JS)*H(KS)
  300 H(JS)=A(N1,JS)-SUM
      J55=J55+1
      IF(20-J55) 302,302,303
  302 IJS=2
  303 RETURN
      END
```

FIGURE D-10 (cont'd)

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